IART®

INTERNATIONAL ASSOCIATION OF REBREATHER TRAINERS

SUBMATiX

SCR 100 ST
User Course Manual

English Edition

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DIVE INTO THE FUTURE - TODAY

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SUBMATiX

SERIES

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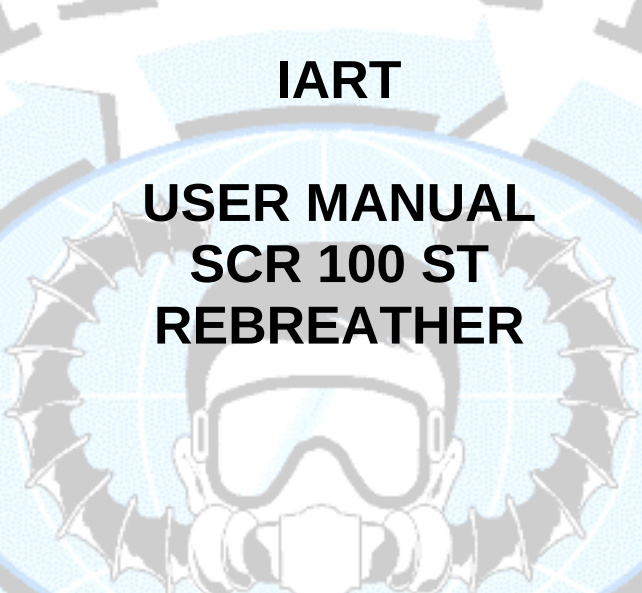
USER MANUAL
SCR 100 ST
REBREATHER



Adapted for IART
Neil Matthews

Level I

2008 Edition

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Please note:

The utmost care has been taken in the preparation of this manual. We cannot however accept any responsibility or liability for any errors, omissions or alterations, nor for any consequences possibly arising through use of, or dependence on any information contained in this manual.
The Author and IART HQ are thankful for any observations from the reader concerning corrections or for any new, relevant material.

Note: Do not attempt to learn to dive with the SUBMATIX using only this manual! This manual is only to be used in conjunction with an IART approved training course.

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A word of warning from the manufacturer:

For your safety, please pay attention to the following directions for use!

The SUBMATIX SCR 100 ST is a unique, state-of-the-art, semi-closed circuit Nitrox rebreather. It is designed and built for recreational diving only (with nitrox to a maximum depth of 40 metres). Using the Submatix SCR 100 ST the diver is only permitted to start the dive at the water surface. The unit must be back-mounted. It uses two separate cylinders filled with pre-mixed Nitrox. The gas volume of these cylinders is not conceived for emergency situations!!!

While its proper use can provide for an enhanced recreational scuba experience, you must understand that, as with all rebreathers, the SCR 100 ST has certain characteristics which can lead to serious injury or death. It must be used correctly. It is important to avoid breathing from the unit when the mix gas tanks are closed or empty! Before every dive all items on the pre-dive-checklist must be completed and be ok!

It is critically important not to attempt to use an SCR 100 ST without first having been trained and certified in its use. You must receive training from a nationally recognized certification organization such as IART.

This IART manual is designed to be a guideline to the proper use of your SCR 100 ST. It is not a substitute for thorough, appropriate practical training and certification in the use of this rebreather. Under no circumstances should the SCR 100 ST be used by anyone who has not been trained and certified to use it.

It is extremely important that you read and understand every aspect of this manual. Should you not thoroughly understand any aspect covered by this manual, please ask your IART instructor for clarification or contact your local SUBMATIX training center.

This manual will also provide you with the necessary manufacturer's guidelines for maintenance and service. These guidelines must be strictly followed, to avoid serious injury or death.

This device must only be used for the purposes specified herein and the security data sheet as well as the product information regarding the use of the carbon dioxide absorber must be strictly adhered to!

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Foreword

The stillness

…is a silence, which opens human’s eyes and ears to another world.

Dear divers,

For good reason you can hear from nearly every diver, who has already dived with a Rebreather, how wonderful the peaceful, bubble-free floating through the underwater world can be. Though not new in concept, this particularly quiet way of diving is redefining our sport by allowing us to gain a more intensive perception of nature. The pros of rebreather diving are irrefutable arguments for a constantly growing fan club spread around the globe.

The prerequisites for taking up this sport are, in addition to the right mental attitude, a well-trained and safe approach to the handling of such fascinating equipment.

You have already made the most important first step in this direction with the completion of a recognised Nitrox Diver course. The knowledge you acquired from that course will prove invaluable to gaining a thorough understanding of rebreather technology and how to safely employ it.

The additional theoretical knowledge will be gained through both instructor presentations and also by home study of this manual. Self-test questions will allow you to assess your own progress. This manual will present you, in a clear and simple form, the knowledge that you will need to become an enthusiastic Submatix rebreather diver. As each rebreather has its own specific features we would like to point out that the contents of the manual relate exclusively to the use of the Submatix rebreather, even if much of the information is general to all rebreathers.

The theory is, however, just one side of the coin. Practical application is equally important and you will have the opportunity to gain this under the guidance of a qualified, Submatix authorized, IART instructor.

We wish you lots of exciting dives

Yours

Uwe Lessmann and Torsten Kraushaar

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Warning and safety information

Important:

Diving has inherent dangers. Do not attempt to dive with a semi-closed rebreather without proper instruction from a diving Instructor specifically qualified for this unit. Ignoring this advice may place you in danger of injury or lead to fatal consequences.

Diving with a semi-closed rebreather requires an all-encompassing training to enable the possible dangers to the diver to be recognised and as far as possible avoided.

Even if you have substantial experience as an “air-diver”, with a rebreather you are once again an absolute beginner! It can lead to life-threatening situations if you think that your former experience is adequate to deal with a rebreather. Develop your diving abilities with the rebreather slowly and carefully, increase your depth limits very slowly and don’t overestimate yourself!

Never dive alone!

Care of equipment:
Avoid contaminating any high or medium pressure hoses or valves that are to be used in contact with oxygen or Nitrox, with oil, fat, mineral or silicone Grease. There is a risk of combustion and explosion!

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A Pre-requisites, course content and course standards

Course pre-requisites:
To participate in this course a minimum certification of IART Advanced Nitrox Diver or equivalent, as well as at least 50 logged dives. The participant must be at least 18 years of age and must present a valid diving medical certificate. Should a Nitrox certification fail, then the possibility exists to complete this training as an additional module prior to the rebreather course. Please consult your IART instructor for further details.

Course structure:
The course participant must undertake the training, by signing the special liability release form, exclusively at his/her own risk.

The training reflects the standards required by the manufacturer of the rebreather. IART is authorized by the manufacturer to conduct this training. This manual is constantly revised and improved in consultation with the manufacturer to reflect new developments resulting from technical improvements or gained through dive experience. You will receive the current edition from your IART Instructor. Older editions should not be used.

The **Submatix SCR - Level I** course trains and certifies the user to dive within no-decompression limits to the maximum safe depth of the Nitrox mix used.

Course Overview:

Theory Presentation:
- Familiarisation with all rebreather components
- Dive planning and execution, Nitrox theory
- Proof of knowledge (written test) covering theory, dive planning and execution, emergency management and rebreather components, concludes the theoretical development.

Practical Training:
- Equipment preparation, care and maintenance
- Dive planning and execution
- Diving techniques and their application in open water
- Emergency management
- Proof of successful completion of all required training exercises.

Certification:
For this training course the current IART standards, manuals and fees listed on the training centre’s application form are binding. All IART instructors must abide by current IART standards, as laid out in the Instructor documents available in the members download centre, when certifying students.

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B Course Objectives

The aim of this course is to train the participating “Submatix” diver to:

Become a knowledgeable, disciplined diver, well-informed on the use of semi-closed rebreathers in respect of

- The physiological factors
- The possible dangers and mistakes
- The dive planning
- The handling of equipment
- The practical dive conduct

Using up-to-date education aligned with the currently accepted methods and guidelines.

This objective will be achieved through both theoretical and practical training modules

C Assessment and Certification

The course participant proves through completion of a **written exam** that he/she has gained the necessary knowledge to dive with the unit safely. Through **open water assessment dives**, the participant proves his/her competence in equipment preparation, use, control in emergency situations and care and maintenance of the unit following the dive. Successful completion of each section of the training will be documented on the quality control forms found in **appendix IV**.

Should the participant fail to achieve any of the defined objectives or demonstrates conduct that could jeopardise his/her own safety, the instructor is obliged to carry out remedial training until the required standards have been met or refuse certification.

After successful completion of both the theoretical and practical training, the participant will be issued the SUBMATIX SCR Level 1 User certification permitting him/her to both dive and purchase the unit.

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Part I General Theory

Module D1 History of Rebreather Diving

1879 Working with the Siebe & Gorman Company, Henry Fleuss constructs a closed breathing system for use in mine-rescue.

1904 Siebe & Gorman patent "Oxyligth" CO_2 absorber.

1926 The Draeger Company develop the "Badetauchretter", a closed oxygen system utilising a breathing lung, chemical absorber and oxygen cylinder.

1939 During the war years various oxygen rebreathers are developed by the British, Italian and German Navies for mine-laying and manned-torpedo operations.

1952 Working with the Draeger Company, Hans Hass develops the "Kleintauchgerät 138"

1953 Appearance of the "Leutnant Lund II" oxygen rebreather. A few of these units can still be found in working order!

1969 Draeger launches the semi-closed “**F**ertig**G**as**T**auchgerät” FGT-1 onto the market. Modified over the years, this unit is still used by military mine-laying divers.

1970 Walter Stark produces the "Electrolung" - the first rebreather controlled electronically. However, the electronics prove so unreliable that the unit is withdrawn from the market one year later.

1975 The "LAR 5" (**L**ungen**A**utomatisches **R**egenerationssystem), an oxygen rebreather, is produced and exclusively designated for military special-forces activities.

1995 The semi-closed Draeger "Atlantis" is launched onto the recreational diver market.

1997 Draeger undertake a number of improvements to the Atlantis and relaunch it under the name “Dolphin”.

1998 After undergoing an intensive 6 year development, the *INSPIRATION* closed circuit rebreather becomes available to the recreational diving market.

1999 In the same year Draeger launch the “Ray”. Smaller and compacter than all previous SCR models.

2004 Aided by an EU-development project grant, the production model of the “Submatix 100” Rebreather achieved a CE-rating in April 2004.

2008 Submatix now has both SCR and CCR versions of its rebreather available throughout Europe.

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Module D2 General Observations

In both recreational and professional diving alike, self-contained, lightweight equipment has become the norm. Thereby the parameters of the planned dive determine the amount of gas (size and number of cylinders) to be carried.
With open circuit systems the diver receives fresh gas with every breath and releases this gas into the surrounding environment with every exhalation. Depending on depth and the level of activity this one-off use of the gas demands a considerable gas supply.
However as the human body only uses the oxygen content within the gas (between 0.3 and 2.5 l/min depending on work-load), the majority of the carried gas is wasted. As depth increases we move even further from the optimum usage of the carried gas as the O_2-consumption remains unaffected by the increase in ambient pressure. (See **module D7** page 16)

To improve the scope of self-contained equipment and make the use of the carried gas more economical, we have the option to use either semi-closed or closed circuit rebreathers.

The method used for supplying fresh gas further subdivides these units into mechanical or electronic categories. In all cases the aim is to optimise the gas mix to enable longer no-stop times in the respective depths. Due to the reduced gas consumption, the amount of gas carried can be reduced so that rebreathers can generally be built in a compact and relatively lightweight form.

Overview of Self-Contained Underwater Breathing Apparatus

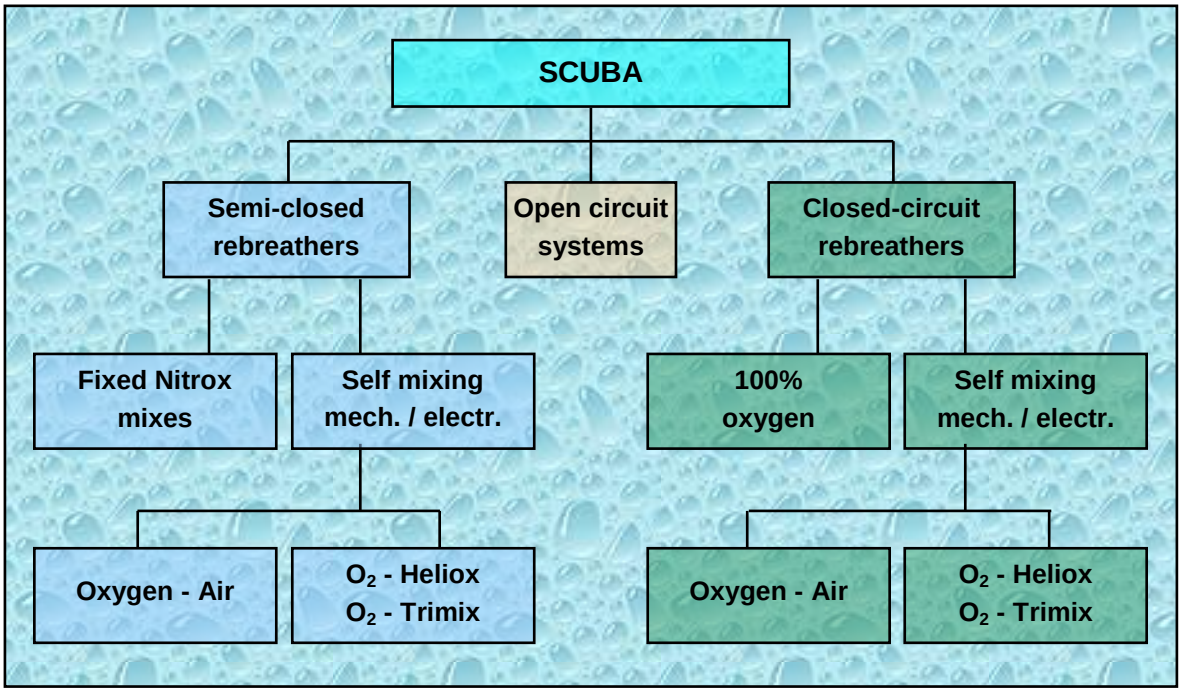

Fig. 1

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Module D3 General Principles of How Rebreathers Function

At the end of this module you should be able to explain the particularities and principle functions of rebreathers.

Broadly speaking rebreathers are comprised of two gas supply systems:

- The fresh gas supply (High/medium pressure system)

The breathing gas, either as a pure gas or as premixed NITROX, flows from one or more storage cylinders via a pressure reducing valve and (in a *closed* system) a demand valve or (in a *semi-closed* system) a “constant flow” dosage into the loop. With passive units the injection of fresh gas must be performed manually.

- The loop (Ambient pressure system)

The breathing gas now passes via a convoluted hose through a gas- and watertight mouthpiece into the lungs of the diver. The gas flow direction is determined by two one-way, non-return valves mounted one on each side of the mouthpiece. These valves also help to keep the respiratory dead space as small as possible.

The exhaled gas then passes through a loop integrated absorber canister, where the now present 4% carbon dioxide is chemically bonded with the absorber granulate. During this process the carbon dioxide reacts with the alkaline hydroxide to form sodium carbonate, water and, as this is an exothermic reaction, also heat.

General principles of how a rebreather functions.

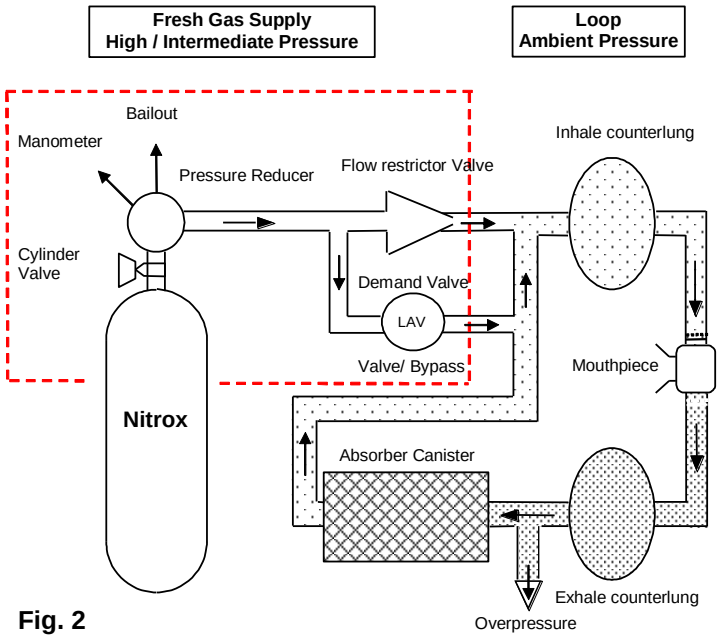

Fig. 2

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Mounted on the exhale side of the loop there is an over-pressure valve that releases excess CO_2 rich gas into the surrounding environment. The over-pressure valve plays a particularly significant role as it influences, depending on its pressure setting, the adequate filling of the counterlung and also the breathing comfort.

To now replace the used O_2 content as well as the lost volume in the loop, fresh gas is mixed into the remaining loop gas either via a demand valve or a constant flow supply as mentioned above. Units utilising a constant flow supply are however equipped with a bypass valve to enable a fast loop flush.

With closed circuit units pure oxygen is fed into the loop, controlled by oxygen sensors and electronics that interpret the sensor outputs to maintain a preselected oxygen partial pressure throughout the dive. The replenished oxygen-rich gas now flows into the so-called counterlungs ready for the diver to inhale. The inert gas content in the loop remains unaffected as it plays no role in the metabolic process. See **fig. 2**

General advantages and disadvantages of rebreathers

General advantages:

- Economical gas consumption
- Longer dive times
- Reduction in decompression time possible
- Reduced exhaust bubbles
- Almost silent
- Less body temperature loss due to warm loop gas
- Less dehydration due to moist loop gas

General disadvantages:

- Gas supply not available everywhere
- Cylinder filling more complex
- Greater care and maintenance demands
- High initial cost of acquisition
- Extra cost of absorber

The particularities of the various systems will be addressed in the subsequent modules.

Self-assessment quiz

D3 1. Name two types of rebreather
D3 2. List both methods by which fresh gas can be supplied
D3 3. List the components of a rebreather that are not found in open circuit systems.
D3 4. Briefly describe the flow of breathing gas through a rebreather.
D3 5. List 3 advantages of a rebreather

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Module D4 How Closed Circuit O_2-Rebreathers Function

At the end of this module you should be able to explain the general principles behind a closed circuit oxygen rebreather.

Closed circuit oxygen rebreathers (e.g. the “Oxylon” from Poseidon, or the “LAR V” from Draeger) are generally very simple in construction. The counterlung is initially filled with oxygen from the cylinder. During the dive the oxygen is consumed at a rate dependant on the diver’s activity level, and carbon dioxide is exhaled. The exhaled gas passes through an absorber compound where the CO_2 is extracted by a chemical bonding process. The removal of the exhaled CO_2 causes a reduction in loop volume that is compensated for by a demand valve that opens as pressure drops, allowing fresh oxygen to flow into the loop and replenish the volume. The cycles begins anew (see Fig. 3 below). Excess gas does not occur.

Although the nitrogen content in the breathing gas is initially insignificant (assuming the loop has been previously flushed according to manufacturer’s instructions), it increases during the dive due to the desaturation of diffused nitrogen in the body tissues. In intervals of approx. 20 minutes – or more frequently during strenuous activity and raised respiratory minute-volume (RMV) – the loop *must* be completely flushed to prevent the danger of oxygen starvation occurring.

If the system is functioning correctly then the loop is constantly supplied with fresh oxygen via the demand valve. Higher levels of O_2-consumption cause the demand valve to open more frequently, thus shortening the available dive time.

General principles of how a closed circuit O_2 rebreather functions

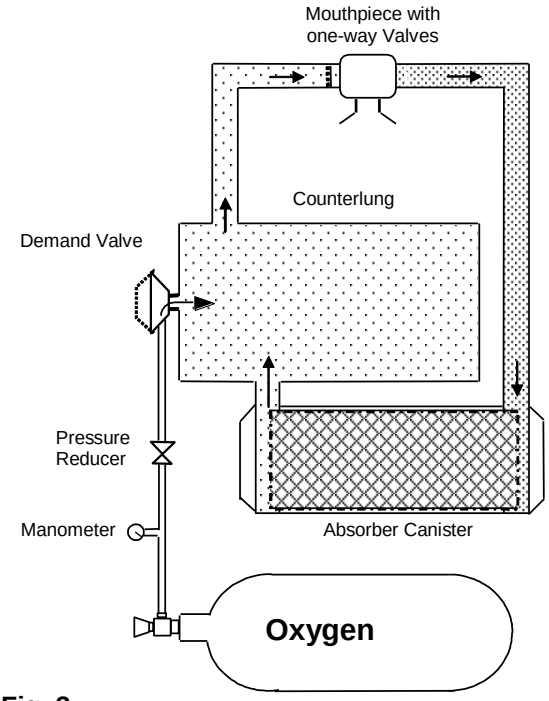

Fig. 3

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Possible problems with oxygen rebreathers are:

- CO_2-toxicity due to faulty or exhausted absorber
- Oxygen starvation can occur if impure oxygen is used or-
- Through inadequate flushing of the loop
- Oxygen toxicity if the very limited depth range is exceeded

Advantages of a closed circuit oxygen rebreather:

- Low weight combined with long dive duration
- Simplicity of design
- The absence of exhaust bubbles.

Disadvantages:

- Gas not always readily available to the recreational diver
- Reduced depth range
- High risk potential if guidelines are not correctly followed

Note: Oxygen rebreathers should only be used in depths of 4 – 6 metres, determined by whether a maximum pO_2 of 1.4 or 1.6 bar is acceptable.

Self-assessment quiz

D4 1. Why is a closed circuit oxygen rebreather “bubble-free“?
D4 2. What can cause oxygen starvation?
D4 3. Why can hypoxia occur even if the gas supply is 100% oxygen?
D4 4. What are the depth limits for an oxygen rebreather?

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Module D5 How Semi-closed Circuit Rebreathers Function

On completion of this module you should be able to explain how a semi-closed rebreather (SCR) functions.

In contrast to closed circuit O_2-rebreathers that are supplied only with pure oxygen, semi-closed units utilise various fixed Nitrox mixes. The chosen nitrox mix determines the MOD and careful dive planning is therefore required. Fluctuations in the oxygen level in the loop are compensated for by a continuous injection of fresh gas calculated to maintain the pO_2 at a safe level. The injection of fresh gas is via a constant flow dosage controlled by a needle valve set either in accordance with manufacturers specifications or user-adjusted to maintain the pO_2 level within safe limits at the chosen MOD and to ensure that the counterlung maintains an adequate volume. The continuous flow of gas should also be sufficient to avoid the possibility of hypoxia occurring during strenuous activity. This constant flow and the fact that on ascent the gas in the counterlung will expand, make it necessary to have an over-pressure relief valve installed so that excess gas can be vented into the surrounding water. On some units this valve is adjustable and the chosen setting affects loop volume and work of breathing (WOB). The correct setting of the over-pressure valve provides an optimum counterlung volume and this in turn keeps breathing resistance (WOB) comfortable.

The amount of gas flowing out through the overpressure-valve is dependant on the chosen dosage and remains relatively constant, but the resulting volume is influenced by the diving depth and this affects the number and size of the bubbles. Minimum bubble formation and the quietest venting of gas are therefore to be expected at the maximum depth for the chosen mix.

Principle Functions of a Semi-Closed Rebreather

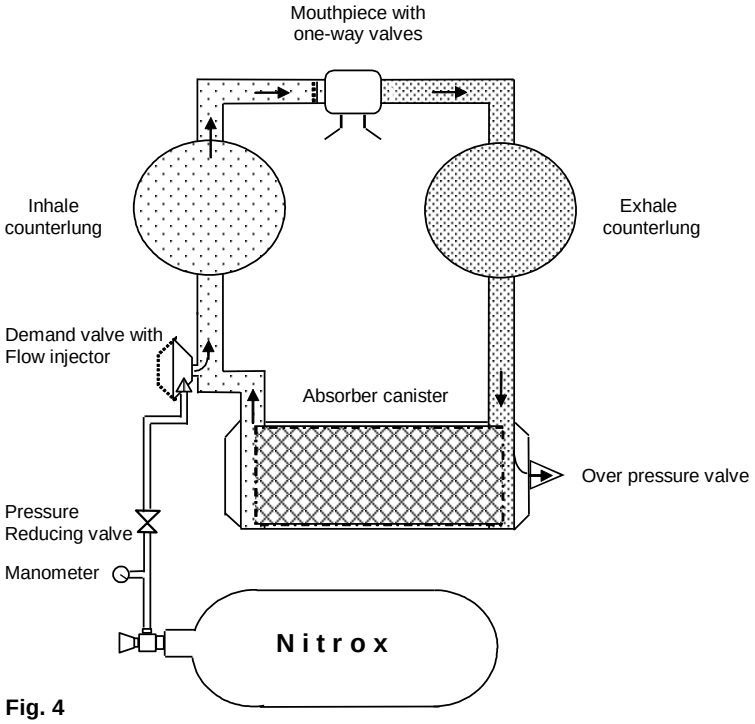

Fig. 4

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Of particular importance is the correct relationship between the selected Nitrox mix and the appropriate flow valve. This is governed by the necessity to guarantee an adequate fresh gas supply even under the most strenuous conditions (higher oxygen consumption). The resultant intensive and life-preserving preparation time needed to calculate this prior to each dive does offer a few advantages. It reduces gas consumption and makes longer dive times possible. For a diver using a semi-closed rebreather with a constant flow of 12 L/min and an oxygen consumption of 1L/min, the use of the breathing gas will be 8 times more efficient than OC. Under heavier workload and/or increased depth, efficient use of the gas supply moves further in favour of rebreathers.

You can read more about this under “Fresh gas supply and gas dosage” in **module D7** page 16.

The potential problems of semi-closed rebreathers, similar to closed circuit units, include CO_2-poisoning, hypoxia and oxygen toxicity.

Advantages of semi-closed rebreathers:

- **Improved gas efficiency**
- **Reduced nitrogen uptake**
- **Reduced exhaust bubbles and therefore quieter**

Disadvantages:

- **Actual gas mix in the loop cannot be guaranteed**
- **Depth limits predetermined by the choice of pre-mix**
- **Fluctuations in pO_2-level, caused by varying activity levels**
- **Therefore additional safety margins are necessary when calculating decompression and CNS exposure**

Self-assessment quiz

D5 1. Why is such a system termed “Semi-closed”?
D5 2. What happens to excessive loop gas?
D5 3. List 3 possible problems associated with semi-closed rebreather diving.
D5 4. List 3 advantages of semi-closed rebreathers.

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Module D6 Gas Consumption and Efficiency

On completion of this module you should be able to explain why gas consumption differs between SCR and open circuit systems.

6.1 Gas Efficiency

With an open circuit system, the diver is supplied with the required volume of fresh gas related to his breathing rate and the actual ambient pressure. The gas consumption is directly related to his RMV and the depth of the dive. However, as the body’s need for oxygen remains relatively constant and largely unaffected by depth, the only factor that governs the actual efficiency of gas consumption is the metabolism of oxygen. As the following table indicates, OC air diving has a low efficiency rating.

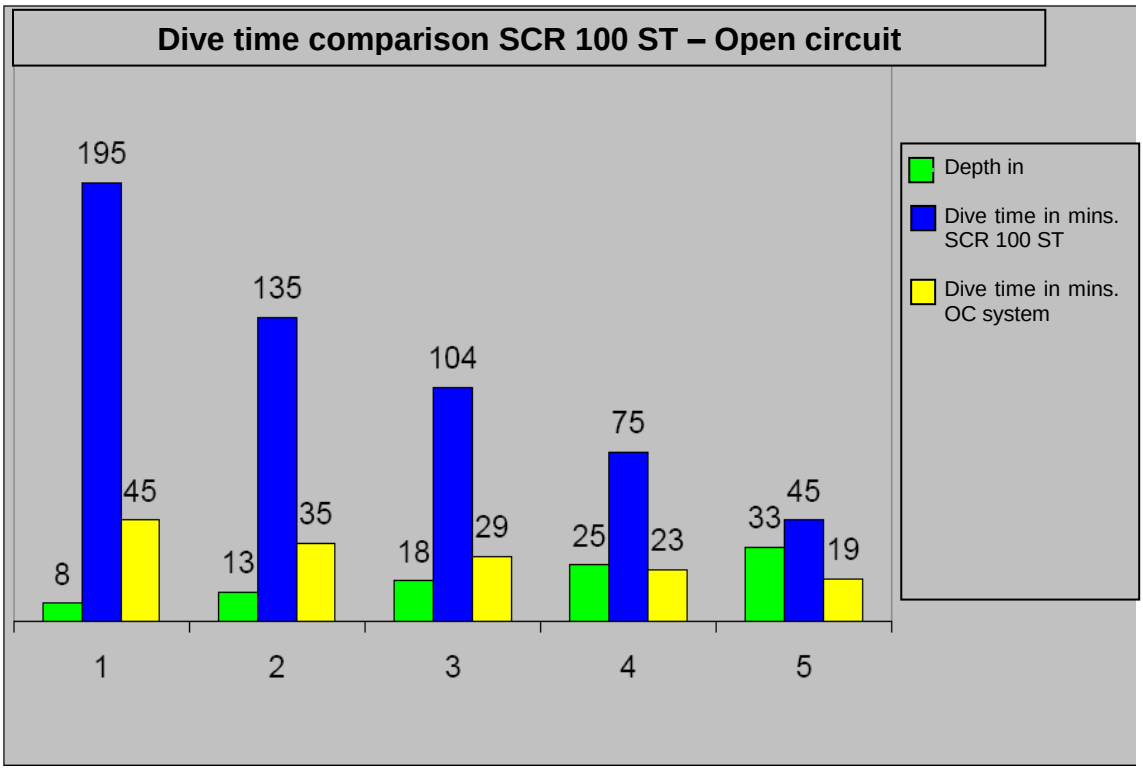

Table 1

Semi-closed rebreathers offer the possibility to repeatedly re-breathe oxygen-rich mixes and thereby greatly improve gas consumption efficiency. The higher the O_2-content, the more economical the consumption rate will be. The best efficiency is gained by closed-circuit units.

6.2 Gas Consumption

Although gas consumption in “constant-flow” SCRs is theoretically unaffected by the depth, it is nonetheless necessary to use higher dosages for greater depth ranges in order to supply the diver with sufficient oxygen at all times during the dive. Gas consumption is therefore primarily a function of flow rate volume and not the actual respiratory minute volume of the diver. Greater depths require, due to the lower O_2 content in the appropriate selected Nitrox mix, a higher constant flow dosage, which in turn results in a higher gas consumption rate. The inadvisable but, by open circuit divers, often favoured “skip-

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breathing” technique has no influence on gas efficiency with SCRs due to this constant flow of gas. It only adversely affects breathing comfort.

Approximate values for oxygen consumption levels:

- At rest ca. 0.5 l/min
- Normal activity ca. 1.0 l/min
- Average workload ca. 1.25 l/min
- Strenuous workload ca. 2.0 l/min
- Extreme activity* ca. 2.5 l/min

(*trained athlete)

Comparison of the potential dive times of each system

Semi-closed System* 4l / 200 bar (30 bar Res.)	Constant-Flow (O_2-consumption 1.25 L/min)	Max. Depth	Dive time (minutes)
Nitrox 80% O_2	3.0 bar L/min	10 m	226
Nitrox 60% O_2	5.0 bar L/min	16 m	135
Nitrox 50% O_2	6.0 bar L/min	22 m	113
Nitrox 40% O_2	10.0 bar L/min	30 m	68
Nitrox 32% O_2	15.0 bar L/min	40 m	32
Open circuit 12l cylinder; 200 bar (30 bar Res.)	RMV	Depth	Dive time
Air	20 L/min	10 m	51
		16 m	40
		22 m	32
		30 m	26
		40 m	20

Table 2

*The actual dive time will be reduced through gas loss caused by mask-clearing, loop flushing, fast descents and saw-tooth profiles.

Self-assessment quiz

D6 1. Which two factors determine gas consumption when breathing open circuit?
D6 2. Which factor primarily determines the gas efficiency of an SCR?
D6 3. What determines an optimum use of the gas supply?
D6 4. Which type of rebreather offers the best gas efficiency?

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Module D7 Fresh Gas Supply and Gas Dosage

On completion of this module you should be able to explain the particularities of the fresh gas supply and the gas dosage control.

7.1 Fresh Gas Supply

There are a number of possibilities of providing fresh gas to consider: manual, constant flow and demand flow.

Manual fresh gas supply
Here the diver supplies the loop according to his needs by manually injecting gas from the carried gas cylinders. The technique demands a solid training and permanent observation of the loop mix in order to prevent oxygen starvation from occurring.

Constant flow fresh gas supply
Here fresh gas flows into the loop through fixed or adjustable needle valves at a steady rate throughout the dive. The rate of constant flow necessary depends on the oxygen content of the gas and from the actual oxygen consumption rate of the diver. The gas flow must be set high enough to ensure that sufficient fresh oxygen is provided even if the consumption rate of the diver climbs due to greater exertion and even in shallow depths. Under no circumstances should the loop oxygen partial pressure be allowed to fall below 0.16 bar!

As an average person, depending on the level of activity, needs between 0.3 – 2.5 litres of O_2 per minute and the flow rate must be set to cope with the higher values, it means that most of the time too much gas will flow into the loop and this, unused gas, must be allowed to vent via an over-pressure valve (OPV) into the surrounding environment.

Examples: Draeger FGT, Draeger Dolphin, Draeger Ray, Submatix SCR 100 ST

The gas supply to such units should always be switched on and off directly before the start and end of the dive to avoid unnecessary gas wastage caused by the constant flow.

Fresh gas via a demand valve - ADV
Fresh gas supplied via a demand valve is usually incorporated in addition to a constant flow valve. The ADV is often similar in construction to a regulator second stage and it is usually positioned in the counterlungs or very close to them, so that a pressure reduction is quickly registered and compensated for. This is often necessary during fast descents or when gas is vented from the loop during mask clearing and following a diluent loop flush.

To provide a semi-closed system with the optimum constant flow rate it is necessary to take into account the following parameters.

- O_2-content of the premixed cylinder
- The gas constant flow rate through the dosage regulator valve (bar l/min)
- Maximum O_2-consumption of the diver (litres/min)

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The fresh gas supply must be so calculated that, even with an unexpected increase in workload, (e.g. caused by unexpected stress factors) the loop oxygen content will not sink below 16 Vol%. This value represents the physiological lower limit of tolerable pO_2 needed to avoid the onset of hypoxic symptoms.

The choices as to what mix to use and how high the level of fresh gas supply (constant flow rate) should be, are not normally determined by the expected work-load factor. This would demand extensive knowledge of the diving conditions and of the individual oxygen consumption rate for each respective diver. The choices are rather more a compromise between an average high consumption and an average economical consumption rate. In this way, we achieve on one hand a greater safety factor for the diver and on the other hand, the benefits of noticeably more efficient gas usage are only marginally reduced

Loop oxygen levels related to the actual O_2-consumption			
O_2% of the premix		O_2-consumption (Workload)	O_2% in the loop
32%	15 l/min	0,75	38,0
		1,25	26,0
		1,5	24,0
		2,25	20,0
40%	10 l/min	0,75	35,0
		1,25	31,0
		1,5	29,0
		2,25	23,0
50%	6 l/min	0,75	43,0
		1,25	37,0
		1,5	35,0
		2,25	20,0
60%	5 l/min	0,75	53,0
		1,25	47,0
		1,5	43,0
		2,25	27,0

Table 3

As stated above, oxygen consumption and workload are directly related and influence not only the oxygen content but also the inert gas content in the loop. At high workloads the O_2-concentration in the loop will sink and the nitrogen content simultaneously increases resulting in a shortening on the remaining no-stop time or increase in the necessary decompression schedule. Lower O_2-consumption rates reduce decompression requirements.

Note!

- **The work load level will affect the oxygen content in the loop mix.**
- **The oxygen concentration in the loop is *always* less than in the Nitrox cylinder.**
  (*Exception:* After flushing, the counterlung will have the same concentration of oxygen as in the supply gas cylinder)
- **As a result equivalent air depths, no-stop or deco- times will be affected.**
- **Each Nitrox mix requires a specific constant-flow dosage to guarantee the minimum necessary O_2-content in the loop! Each time the gas mix is changed the dosage regulator valve *must* also be exchanged!**

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7.2 Gas dosage

With rebreathers the dosage of fresh gas can take place in various ways:

1. By using a premixed supply cylinder with
   a) Consumption *dependant* dosage for closed circuit units
   b) Consumption *independent* dosage for semi-closed units

2. By feeding pure- or mixed gases into the unit
   a) Dosage for closed circuit units is dependant on consumption and depth
   b) Dosage for semi-closed circuit units *independent* of consumption and depth

1a) Consumption *dependant* dosage in closed circuit O_2 rebreathers

Consumption-dependant dosage is used in closed circuit oxygen rebreathers. As the diver metabolises oxygen the counterlung slowly loses volume. This reduction is `sensed´ by a demand valve, which then opens as an exactly defined pressure drop is reached, allowing just enough fresh gas to flow into the counterlung to re-establish the desired volume.

Consumption-dependant dosage is therefore the most economical dosage method and it also allows truly `bubble-free´ diving. Units like the “Oxylon” from Poseidon or the LAR V from Draeger work according to this principle. Such units are most commonly used for military activities.

Advantages of consumption *dependant* dosage:

- Most economical use of gas supply
- Bubble-free

Disadvantages:

- More complex dive procedure due to the need for gas flushing
- More restrictive depth range

1b) Consumption independent (constant flow) SCR’s

In consumption independent semi-closed units, fixed pre-mixed gas flows continuously via dosage nozzles into the breathing loop. These so-called dosage nozzles are connectors or needle valves that are constructed to allow a constant flow volume appropriate to a particular gas mix.
If a switch to another mix is necessary, then it is also **essential** to exchange the dosage nozzle to one specific for the new mix. The correct flow must then be confirmed using a flow meter.

From a technical point of view consumption independent dosage is the simplest and also the most reliable solution, as only a few working components are needed. In financial terms, the use and maintenance costs of rebreathers with this dosage method are among the most economical.

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Advantages of consumption *independent* dosage:

- Technically simple - safe and reliable in use
- Pre-set dosage valves for the various standard Nitrox mixes

Disadvantages:

- Filling logistics
- Elaborate constant flow measurements
- Complex decompression calculations

2a) Consumption *dependant* dosage in closed circuit rebreathers

For depth and consumption dependant dosage both pure and mixed gasses are needed and these are either mechanically or electronically adapted within the unit to the actual diving depth.

When an individually selected and constantly held oxygen partial pressure is maintained by adding diluent gas in the form of air or helium, a constantly changing gas relationship occurs which is optimized to the depth. The maximum depth limits are therefore set by the chosen diluent gas to be used.

With electronically controlled rebreathers the oxygen partial pressure is measured by the use of one or more O_2-sensors that regulate the consumption dependant injection of fresh oxygen into the loop. Due to this consumption-based technique, closed circuit units are among those with the lowest gas consumption. On the other hand, running costs and maintenance requirements are significantly higher.

Advantages of consumption *dependant* dosage:

- Most economical gas consumption
- Bubble-free
- Greater possible depth range
- Longer no-stop times due to the constant pO_2 principle

Disadvantages of consumption *dependant* dosage:

- Greater maintenance required
- Higher running costs due to need for O_2 sensors and power supply (batteries)
- Incorrect gas mixing should the sensors fail

2b) Consumption *independent* dosage using pure and mixed gasses

A further gas supply possibility for semi-closed rebreathers is constant flow using both pure and mixed gas.
Two independent systems, e.g. an oxygen and an air supply with two separate needle valves, deliver the optimum Nitrox mix for a particular depth. Additionally it is also possible to reflect personal requirements and workload factors in the adjustment of the gas flow volume level.

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The constant flow setting of each of the needle valves must be made prior to commencing the dive by using an extremely accurate flow meter that is capable of displaying the necessary gas volume in l/min.
Some units even allow for the depth to be reflected in the mix. In such cases oxygen dosage is designed to be depth *independent* whereas the dosage of the inert gas (regulated by the first stage intermediate pressure) climbs with increasing depth. The maximum depth limits are once again governed by the constitution of the inert gas used.

Advantages of consumption *independent* dosage:

- Very economical gas usage
- Almost bubble free
- Greater depth range
- Longer no-stop times

Disadvantages:

- More complex dive planning (gas-flow calculations)
- Need for careful adjustment to dosage regulator valves (needle valves)
- Greater maintenance due to larger number of system components

Self-assessment quiz

D7 1. List the three parameters that must be taken into account when setting the constant flow dosage level?
D7 2. What is the minimum tolerable loop O_2-level?
D7 3. Which factor changes due to high exertion and what are the resulting effects?
D7 4. Explain why rebreather diving with just air is not possible
D7 5. List two methods of gas dosage.
D7 6. Which types of gas are used in a consumption dependant *CCR?*
D7 7. What essentials must be observed following a switch to a different gas mix?
D7 8. How can the correct constant flow gas volume be checked?

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Module D8 Respiratory Physiology

At the end of this module you should be able to explain the principles of respiration.

The most important component of any breathing gas is the life-supporting oxygen. Through combustion the burning of oxygen provides the energy source by which all body functions are maintained. The need for oxygen varies from moment to moment dependant on physical activity levels and also varies from organ to organ. The organs also react differently to a lack of oxygen. The most sensitive being the brain and spinal cord. Tissues receiving a lower blood supply such as fat and bone cells are more resistant to oxygen starvation and can endure longer before suffering damage.

When we inhale atmospheric gas passes via the airways into the lungs where it comes into contact with the alveoli; the interface separating it from the bloodstream. Here, via a thin membrane wall, O_2 diffuses from the inhaled gas into the bloodstream and in exchange CO_2 diffuses from the blood back into the lungs and ultimately back into the ambient environment. The surface area of the alveoli involved in this gas exchange can encompass, in a full-grown adult, as much as 100 to 200 m^2.

From the 21% atmospheric oxygen inhaled, only a small amount is actually passed through the alveoli into the blood. The greater part of the inhaled oxygen is simply exhaled again. Approximately 80 – 82 % of the dissolved oxygen in the blood is metabolised and converted into carbon dioxide (metabolic conversion rate). This carbon dioxide “waste” is expelled with each breath.

If now, through increased workload, a great deal of oxygen is metabolised, the rate of CO_2 production will similarly climb. It is directly related to the actual oxygen consumption level. The result is an increase in ventilation frequency to enable the produced CO_2 to be exhaled and to provide the body tissues with a fresh supply of oxygen.

The respiratory rate is primarily governed by the blood CO_2-level and only to a much lesser extent by the blood O_2-content. Thus the frequency with which we breathe depends to a great extent on the rate of CO_2-production in the body and not on the shortage of O_2-concentration in the bloodstream.

Self-assessment quiz

D8 1. Where does the exchange of O_2 and CO_2 take place?
D8 2. What determines the level of oxygen metabolism?
D8 3. How is the respiratory rate primarily controlled?
D8 4. What effect does the level of CO_2 have on breathing?

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Module D9 Oxygen Metabolism

At the end of this module you should be able to explain the features of oxygen metabolism.

Oxygen is the life-supporting element in all breathing gas mixtures. Chemically bonded to haemoglobin, oxygen is transported by the red blood cells through the bloodstream to all body tissues. During normal circumstances the haemoglobin is approx. 97 % saturated with oxygen.

At greater altitudes, one can survive on oxygen partial pressures (pO_2) as low as 0.1 bar. When diving however, a minimum pO_2 of 0.16 bar should be adhered to in order to avoid oxygen starvation (hypoxia) from occurring. (See **module D10** page 23)

Under pressure however, too much oxygen can also have damaging effects on the body. The type of effect is dependant on two factors: exposure time and partial pressure. Oxygen partial pressures above 0.45 bar lead with *longer* exposure to pulmonary damage. (See **module D11** page 24)

Exposure to levels above 2.0 bar pO_2 leads to oxygen toxicity of the central nervous system (CNS-toxicity) with resultant convulsions affecting the whole body.
(See **module D12** "Paul-Bert-Effect" page 25)

For the sport diver, the danger of oxygen lies in its effect on the central nervous system. CNS-toxicity is a deadly danger that causes uncontrollable spasms which can lead to the diver losing grip on the mouthpiece and drowning. Decades of mixed gas diving experience has led to the recommendation that pO_2 should never exceed 1.6 bar. Furthermore, with raised physical activity and/or raised CO_2 levels, pO_2 should not exceed 1.4 bar.

As a general rule the acceptable limits are:

Minimum 0.16 - Maximum 1.6 bar.

Self-assessment quiz

D9 1. Which agent binds O_2 in the blood supply?
D9 2. What is the most dangerous aspect of oxygen toxicity?
D9 3. With raised exertion levels, the maximum pO_2 should be?
D9 4. What are the rule-of-thumb limits for pO_2 levels?

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Module D10 Hypoxia

On completion of this module you should be able to explain the causes and symptoms of hypoxia and know when they are likely to occur.

Hypoxia is one of the limits that we as rebreather divers and as mixed gas divers must very closely observe. An inappropriate choice of mix and a shallow diving depth can, under certain circumstances, lead to an O_2-partial pressure less than 0.21 bar. Although the human body can tolerate lower levels they should not be allowed to drop below the absolute limit of 0.16 bar. The first signs of an onset of hypoxia could be:

- Tunnel vision
- Tingling sensation
- Warm feeling
- Loss of concentration

The intensity of these symptoms will vary from individual to individual and in some cases may not necessarily appear at all. If the partial pressure falls below 0.16 bar, this will lead eventually to unconsciousness (0.10 bar) and further drops lead to brain damage, coma and ultimately death. For the diver, unconsciousness - due to the risk of drowning – is already extremely dangerous! However, if this situation is corrected before the onset of unconsciousness, the body generally recovers within seconds.

Note:
Often there is no recognisable symptom that warns of imminent unconsciousness!

Therefore it is of great importance, as with hyperoxia, that every rebreather diver understands the limits and possible causes of hypoxic situations. Through careful dive planning, preparation and execution, the diver must exclude the chance that a hypoxic situation can occur.

Note:
Commencing a rebreather dive with a filled loop but closed cylinder valves will lead quickly to a hypoxic situation. To avoid this, strictly adhere to the pre-dive check list.

Emergency assistance after recovery from water:
If breathing, the casualty should be administered 100% oxygen without delay. If resuscitation is required, perform oxygen-enriched mouth-to-mouth via a continuous-flow oxygen mask or preferably administer 100% oxygen via a positive pressure bag. DAN O_2 units are suited for all applications.

Self-assessment quiz

D10 1. What does the term hypoxia mean?
D10 2. Below which partial pressure do we speak of hypoxia?
D10 3. Is the risk of hypoxia depth dependant?
D10 4. List 3 possible symptoms of hypoxia.
D10 5. Which of these is particularly dangerous to a diver?
D10 6. What treatment should be applied following a hypoxia incident?

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Module D11 Hyperoxia – Pulmonary Toxicity

On completion of this module you should be able to explain the cause and symptoms of pulmonary toxicity (the Smith-Lorraine effect).

Generally, pulmonary toxicity is of little concern to the average recreational diver. It occurs only after extended exposure to a pO_2 in excess of 0.5 bar. It would be necessary to complete a series of dives with long decompression requirements over a number of days before the first symptoms would become apparent. Even then, in comparison to CNS toxicity, the symptoms are at most unpleasant rather than life-threatening. Symptoms are:

- Discomfort in the lungs
- Inflammation of the respiratory tract.
- Dry cough
- Shortness of breath
- Fatigue

Shortness of breath and fatigue occur because the alveoli walls thicken and this hinders the normal diffusion of O_2 into the tissues. Treatment of the symptoms is not usually necessary. Recovery will slowly take place by simply breathing normobaric air and not diving for a day or two.

For the rebreather diver the following therefore applies: As long as one remains within the oxygen exposure limits, ***pulmonary toxicity*** 'will have no damaging effects.

See **module D18** Calculation of OTU exposure

Self-assessment quiz

D11 1. Does pulmonary toxicity usually represent a real problem for the diver?
D11 2. At what pO_2 level do adverse physical effects begin to become evident?
D11 3. Is this a factor to be considered during recompression chamber treatment?
D11 4. List three symptoms of pulmonary toxicity.

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Module D12 Hyperoxia – CNS Toxicity (Paul-Bert-Effect)

At the end of this module you should be able to explain the term hyperoxia and the cause and symptoms of CNS toxicity.

Whereas an OC air diver only needs to think about his no-stop time and perhaps his level of nitrogen narcosis, the rebreather diver must take other important physiological factors into account. The advantages offered by the use of a rebreather require, on the other side, greater responsibility in the planning and execution of the dive. The life-supporting oxygen that we normally take for granted can, (if MOD's are exceeded or the unit malfunctions), turn itself very quickly into a lethal gas!

Hyperoxia is excessive oxygen at body cell level. A healthy person can withstand for an unlimited period an oxygen partial pressure of 0.45 bar (that is a 45% O_2 content at sea level) without ill-effect. Above 0.5 bar pO_2, and dependant on the actual pO_2 level, exposure time and exertion level, the pulmonary system and the central nervous system can be adversely affected.

At rest, we can even withstand a pO_2 in excess of 2 bar for short periods of time. Tests carries out by the **National Oceanic and Atmospheric Administration** (NOAA), show that our tolerance reduces with greater exertion, exposure to cold temperatures and other physical factors such as an elevated CO_2 level. The tests resulted in a now widely used table of safe time limits for various pO_2 levels.

These exposure limits are only guidelines. Sensitivity to raised pO_2-levels varies from person to person and day to day. Exposure times should be reduced with higher than normal exertion levels.

Therefore, generally a maximum partial pressure of 1.4 bar is advisable and this should only be exceeded in instances where pN_2 is otherwise unacceptably high. I.6 bar should be regarded as the absolute limit for recreational diving.

EXPOSURE TIME LIMITS				
bar	Per Dive		24 Hr. Maximum	
	(Minutes)	(Minutes)	(Minutes)	(Stunden)
1.6	45	0.75	150	2.5
1.5	120	2.0	180	3.0
1.4	150	2.5	180	3.0
1.3	180	3.0	210	3.5
1.2	210	3.5	240	4.0
1.1	240	4.0	270	4.5
1.0	300	5.0	300	5.0
0.9	360	6.0	360	6.0
0.8	450	7.5	450	7.5
0.7	570	9.5	570	9.5
0.6	720	12.0	720	12.0

Table 4

***To calculate the CNS-loading more accurately see **example 1** on page 37 and **Table 6** on page 38, where the CNS values are given in percentage.

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The symptoms of oxygen toxicity can be remembered with the aid of an acronym: **CONVENTID**

CONvulsions	- Muscular spasms affecting the whole body in chronic and tonic phases
Vision	- Tunnel vision
Ears	- A ringing sensation
Nausea	- Vomiting may occur
Twitching	- Often in the cheek, lip or eye muscles
Irritability	-
Dizziness	- General loss of orientation

Although the diver should be aware of the symptoms they may not occur in this order; they may not even occur at all! Therefore they should not be relied upon as an early warning. Even if they do appear, it may already be too late to prevent convulsions and in many cases there will be no warning before convulsions and sudden unconsciousness occur.
Watch out for warning symptoms such as nausea, thumping heartbeat and fast, shallow breathing. If you detect such symptoms an immediate reduction of the O_2 partial pressure by switching mixes or bailing out, and an immediate ascent is the only way to prevent the situation from becoming life-threatening!

At this point be reminded of the importance of "buddy diving"! As has been shown in the past, only a dive partner can prevent such a situation from turning into a fatal accident.

Note:

- **Oxygen convulsions (similar to an epileptic fit) can occur without warning if safe pO_2 levels are exceeded**
- **Should convulsions occur, it takes several minutes following the discontinuation of excessive oxygen for the symptoms to subside**
- **The likelihood of a CNS 'hit' varies from person to person and from day to day!**

There are other contributing factors that raise the susceptibility to oxygen toxicity:

- High exertion level
- CO_2 retention
- Raised or lowered body core temperature
- Pre-existing sickness or illness
- Under medication

Be aware of symptoms such as nausea, thumping heart, fast and shallow breathing. If you notice any of these **you should bail out to air and immediately terminate the dive!**

By observing the following safety precautions the chance of oxygen toxicity occurring is extremely remote:

- Stay within maximum pO_2 depth limits
- Keep within the oxygen toxicity "clock" time limits

Reduce exposure time by raised exertion levels or raised CO_2 levels

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Important:

Always stay within pO_2 limits with regard to level and length of exposure!

Self-assessment quiz

D12 1: The "Paul-Bert-effect" describes?
D12 2: What three factors contribute to hypoxia?
D12 3: State the NOAA time limits for exposure to a pO_2 of 1.3 bar
Per dive: Per day:
D12 4: List the seven possible signs and symptoms of oxygen toxicity.
D12 5: List four factors that raise the sensitivity to oxygen toxicity.
D12 6: How can oxygen toxicity be avoided?
D12 7: What is the best emergency procedure by an excessively high loop pO_2?

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Module D13 Hypercapnia

On completion of this module you should be able to explain the causes and symptoms of hypercapnia and list the consequences that arise.

Hypercapnia is a raised level of CO_2 in the blood. When diving with OC equipment, it is typically caused by "skip-breathing", poorly-maintained regulators or high levels of exertion.

The atmosphere contains only 0.00033 bar CO_2. As we metabolise oxygen and produce CO_2 as a by-product, the partial pressure of CO_2 in the bloodstream increases, triggering our desire to breathe. When the blood pCO_2 exceeds 0.02 bar we react with an increased breathing rate which flushes the CO_2 quicker from the tissues and at the same time increases the oxygen supply. Should a pCO_2 of 0.1 bar be reached, dizziness, headache and a general unwell feeling will occur. By 0.15 bar breathing will be so rapid that it is no longer controllable and cramping can occur. After a number of minutes this will lead to unconsciousness. False breathing technique or increased activity levels will aggravate these symptoms.

Because the rebreather diver exhales his "used" gas back into the loop, the CO_2 must be chemically extracted to avoid hypercapnia occurring. The necessity for this process raises the inherent risk that the CO_2 level could rapidly climb if, for any of a number of reasons*, this chemical extraction does not take place.

***Hypercapnia** can occur in a rebreather when the absorber is:

- Too wet or already exhausted.
- Insufficient or even absent
- Incorrectly packed (too little or too loosely packed absorber leads to gas channel formation and inadequate CO_2 filtration)
- Bypassed through leakage around absorber canister
- Bypassed by re-breathing CO_2 retained in mouthpiece and hoses (damaged or incorrectly assembled one-way diaphragms in mouthpiece)

Note! Overexertion or incorrect breathing techniques amplify the risk of hypercapnia.

Early warning signs to control are:

- Inexplicable shortage of breath or increased breathing rate
- Strong headache
- Nausea, vomiting
- Loss of orientation, irritation, loss of concentration

Beware: **Life-threatening due to sudden onset of unconsciousness!**

Self-assessment quiz

D13 1. Which gas causes hypercapnia?
D13 2. What are the dangers of hypercapnia?
D13 3. State 3 possible causes of hypercapnia in a rebreather:
D13 4. Describe the first-aid measures for CO_2-poisoning:

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Module D14 Nitrogen Narcosis

On completion of this module you should be able to explain whether nitrogen narcosis plays a significant role for the rebreather diver.

As the rebreather diver generally breathes a gas with a nitrogen content lower than when OC air diving, the level of nitrogen narcosis experienced at a given depth will be less than that experienced by the air diver.

At the start of a dive the nitrogen content in the body is balanced with the ambient atmospheric air, in other words 79% saturated. To reduce the body as quickly as possible to the new nitrogen lean mix, the loop should be flushed prior to descent. Due to the reducing partial pressure nitrogen will diffuse from the body tissues into the loop and by flushing this away the maximum gradient can be maintained during equalization. This process does not happen quickly however and continues during the dive itself. Therefore the premixed nitrox injected into the loop continues to be “contaminated” by diffusing nitrogen. It is therefore advisable to flush the loop again during the dive.

However, when using “leaner” mixes (E.g. 32% O_2), combined with a longer stay at maximum depth, the chance of N_2-toxicity occurring cannot be completely excluded. Generally the same rules apply for the SCR-diver as for the air diver: Including no alcohol, no medication!

When diving with oxygen rebreathers nitrogen narcosis is not a significant factor.

Self-assessment quiz

D14 1. Name an advantage that rebreathers have in comparison to open circuit equipment in relation to nitrogen narcosis.

D14 2. Why can nitrogen narcosis largely be ignored when diving with O_2-rebreathers?

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Module D15 Buoyancy Control

On completion of this module you should be able to explain why the buoyancy control of a rebreather differs greatly to that of open circuit equipment

Correct weighting is particularly important. Excessive lead necessitates a high volume in suit or wing at depth and excessive venting and inflation to compensate for depth changes. Higher gas consumption, a head-up swim position and greater drag are the results of overweighting.

The SCR diver is correctly weighted when, with empty suit/wing and an optimum volume of gas in the loop, he just begins to sink. When 3 kg of lead is now added to compensate for nearly empty cylinders and to allow for sufficient suit inflation to provide insulation at shallow depths the weighting should be perfect.

A typical feature of rebreathers is the inability for the diver to exercise fine buoyancy control by inhaling or exhaling. This technique, universally used by all OC divers, does not function for the rebreather diver as the gas inhaled to increase lung volume is drawn from the counterlung which, in turn, loses volume correspondingly. The same applies to exhalation. The gas exhaled returns to the counterlung thus compensating for the reduction in lung volume. Exactly this lack of fine buoyancy control that experienced open circuit divers perform subconsciously, make the first buoyancy control exercises with an SCR a test of patience and often leaves the diver feeling like an “old dog” trying to learn new tricks.

Just as it was in your novice training, buoyancy control is once again hand work and must be relearned. Under no circumstances should you be tempted to control buoyancy by reducing counterlung volume (by exhaling through the nose for example) as this will only cause, in addition to unnecessary gas loss, a deterioration in breathing comfort.

Self-assessment quiz

D15 1: Why is it not possible to adjust buoyancy through breathing control?

D15 2: Why is it not sensible, when swimming over an obstacle, to compensate for positive buoyancy by venting the counterlungs?

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Module D16 Work of Breathing (WOB)

On completion of this module you should be able to explain how breathing resistance can vary and why the position of the counterlung(s) affects the work of breathing.

The breathing resistance of a rebreather changes noticeably dependent on the position of the counterlung(s) in relation to the diver’s own lungs and the volume of gas in the loop. The best position for the counterlung would be directly against the diver’s own lungs as this would avoid changes in the WOB occurring with changes in body attitude. As this is not technically possible, the counterlung is positioned as close as possible to the hydrostatic axis of the lungs. Decisive for the diver (who spends most of the time in a horizontal position), is whether a position on the back or the chest is chosen. This is a dynamic relationship influenced by changes in depth and the position of the diver:

Normal horizontal position: Counterlungs placed on the chest provide for reduced inhalation resistance due to the positive hydrostatic pressure (equivalent to approx. 10 cms in the water column). Conversely the higher pressure in the counterlungs increases exhalation resistance. Counterlung(s) situated on the back provide for increased inhalation resistance due to the negative hydrostatic pressure. Conversely the lower pressure in the counterlungs reduces exhalation resistance.

Vertical swimming position (head-up or head down): Gas in the counterlungs, whether on the chest or back of the diver, rises to the highest point possible leading to a slightly negative hydrostatic pressure compared to the divers lungs. Inhalation effort increases and exhalation effort decreases accordingly. However this is less noticeable than the effect experienced with an OC regulator.

Regardless of position, almost no hydrostatic change in WOB is experienced with counterlungs that are positioned over both chest and back.

Loop Volume: A further criterion for optimising breathing comfort is the actual counterlung volume which should only be enough for 2-3 deep breaths before emptying. If the volume is too high, either due to an incorrectly adjusted over-pressure valve or a fast reduction of depth, the WOB will increase. In contrast an empty counterlung caused by a too-lightly adjusted valve, by descending too fast, by leaks in the loop or by gas loss through frequent mask-clearing, results in discomfort due to increased inhalation resistance.

The CO2-absorber also influences WOB. By its nature it increases WOB but this increase is held within tolerable limits providing the correct absorber is used, is correctly packed and is not exposed to excessive moisture or overused (See Module D17). Only absorber of the type and quantity recommended by the rebreather manufacturer should be used as this will have been chosen to suit the characteristics of the canister design. A further negative influence on breathing characteristics is caused by water ingress into the loop particularly if it reaches the absorber canister. High WOB levels cannot be tolerated over long periods of time. They lead to shallow breathing as the chest diaphragm tires, less effective flow of gas through the absorber and the threat of CO2 retention.

Self-assessment quiz

D16 1: Does a change in swim position noticeably affect WOB? If so, why?
D16 2: List 3 factors that reduce breathing comfort:

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Module D17 Absorber

At the end of this module you should be able to explain the purpose of absorber and the possible dangers arising from its use.

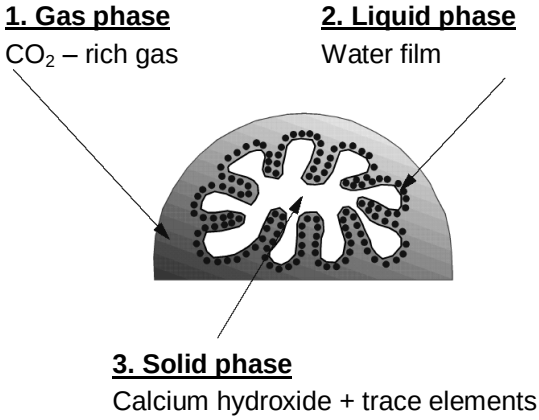
“Absorber is cheap, life is valuable”

One of the most important parts of a rebreather is the CO_2 absorber (often referred to as the “scrubber”). The gas in a semi- or fully-closed rebreather only remains breathable if the exhaled CO_2 is filtered out of the loop. This filtration occurs by molecular bonding of the CO_2 with a special absorber chemical. The canister to hold this chemical is designed by the rebreather manufacturer to optimise the use of the specifically chosen chemical. It is important to use only the recommended absorber as both form and size of the granules influence the contact time and surface area of the chemical with the loop gas. These factors determine the effectiveness of the filter and the WOB. (See **Module E6,** page 75)

The absorber converts the exhaled CO_2 in a series of exothermic (heat-producing) chemical reactions into harmless chalk and water.

CO_2-Absorption can be demonstrated in three simplified steps:

1. **1st Phase – Acid production (gas phase):** carbon dioxide forms carbonate
   $CO_2 + H_2O \leftrightarrow H_2CO_3$
2. **2nd Phase - Neutralisation (liquid phase):** carbonate reacts with the hydroxide alkali to produce sodium carbonate und water
   $H_2CO_3 + 2\ NaOH \leftrightarrow Na_2CO_3 + 2\ H_2O$
3. **3rd Phase - Conversion (solid phase):** Sodium carbonate reacts with the calcium hydroxide to form calcium carbonate. By-product sodium hydroxide
   $Ca(OH)_2 + Na_2CO_3 \leftrightarrow CaCO_3 + 2\ NaOH$



The effectiveness of this process is influenced by temperature, transition time of gas through filter, density of the packed filter, ambient pressure and the moisture content of the chemical. The warmer the chemical the better the CO_2 is absorbed. Therefore a “pre-breathe” sequence prior to diving is highly recommended to both warm the canister and check that the filter is working. In cold water it must be expected that the filter will perform less effectively and a reduction in the length of usage is advisable. Some rebreathers have well-insulated canisters that minimise loss of performance due to cold water.

All of these factors make it difficult to exactly determine the effective filter duration. Numerous tests have also demonstrated that even under identical, controlled conditions (quantity, temperature, pressure, packing-density and CO_2 content) the duration prior to CO_2 “breakthrough” can still vary greatly. A further variable is the level of CO_2 production.

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This varies from diver to diver and from day to day, whereby the level of exertion plays a significant role. The higher the workload the greater will be the O_2 consumption and therefore the higher the CO_2 production rate. Therefore it is wise to plan very conservatively and to always observe the manufacturer’s recommendations! (see **Module E7** page 76)

CO_2-breakthrough during a dive can occur for a number of reasons:

- Incorrectly packed canister (channelling)
- Exhaustion of the chemical due to high exertion levels
- Use of contaminated, wet or already used chemical
- Overextension of the scrubber duration guidelines
- Incorrect absorber chemical

Irrespective of cause the result will be hypercapnia. At the first onset of hypercapnia symptoms bail-out to open circuit immediately and terminate the dive.

Oxygen is metabolised in the body to fuel the tissues and CO_2 is a by-product of this process. **On average 0.8-0.9 litre of CO_2 is produced from 1 litre of oxygen metabolised**. A typical chemical absorber binds approximately 25 litres of CO_2 per 100 grams and break-through is considered to have occurred when the CO_2 in the loop (after passing through the filter) exceeds 0.5%.

Should water come into contact with the absorber not only the performance of the filter will be affected. In addition, with certain types of absorber, there is a risk that the water and chemical will mix and form a caustic solution that in the absence of effective water traps may reach the mouthpiece and be inhaled. This can cause unpleasant burning of the mouth and airways.

Should you experience burning caused by a caustic “cocktail”, bail-out immediately to open circuit and terminate the dive. Thoroughly rinse mouth with plenty of freshwater and spray with Auxiloson. Visit a doctor.

Note!

- **Only fill the absorber canister shortly before the dive.**
- **Avoid using absorber with excessive dust content. The dust may bypass the various traps and combine with condensation to produce a “caustic cocktail”.**
- **Loop flooding can also lead to a “caustic cocktail”.**

Self-assessment quiz

D17 1. What is the purpose of the chemical absorber in a rebreather?
D17 2. Can any brand of absorber be used?
D17 3. List at least two reasons for absorber failure and the consequences thereof?
D17 4. What is a caustic “cocktail” and how can it happen?

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Module D18 Basic Physics review

On completion of this module you should be able to calculate the limits of nitrox as a diving gas.

A few important gas laws need to be considered.

- Atmospheric pressure at sea level ≅ 1 bar
- Per 10m water column we add ≅ 1 bar

⇨ The sum of the above gives the absolute pressure (P)

Therefore in a depth (D) of 30m the absolute pressure (P) is:
3 x 10m water column = 3 bar + 1 bar atmospheric pressure = 4 bar

Written as an equation we have:

$$\mathbf{P = \left(\frac{D}{10} + 1\right) = absolute\ pressure\ (bar)}$$

Example:
What is the absolute pressure in 27m depth?

$$\mathbf{P = \left(\frac{27m}{10} + 1\right) = 3.7\ bar}$$

The equation enables us to determine the absolute pressure for every depth. This is important as we must later calculate the partial pressure of the breathing gas at any given depth.

In reverse we can also find the depth for a given absolute pressure:

$$\mathbf{(P - 1)\ x\ 10 = depth}$$

Example:
At what depth is the absolute pressure 2.4 bar?

$$\mathbf{(2.4\ bar - 1)\ x\ 10 = 14\ m}$$

For nitrox diving we also need to consider **Dalton's Law.**

This states that the total pressure of a gas is the sum of the partial pressures of its constituent gases.

In the case of our atmosphere, 79% nitrogen and 21% oxygen at sea level, the partial pressures are 0.79 bar nitrogen and 0.21 bar oxygen respectively. Thus:

P = 0.79 bar pN_2 + 0.21 bar ppO_2 = 1.0 bar

Note:
The partial pressures of O_2 (pO_2) + N_2 (pN_2) give the absolute pressure (P)

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The **partial pressure** of a gas has a decisive implication for the diver as it has physiological and chemical effects on the body. Usually we know the fraction of the gas (FG) in the mix we plan to breathe (i.e. the % of each gas in the mix). In the case of air this is 21% O_2.
As the effects of any gas depend not on its constituent % but rather on its partial pressure (PG) we must determine a depth to assess the PG and its affects. A simple equation can be used:

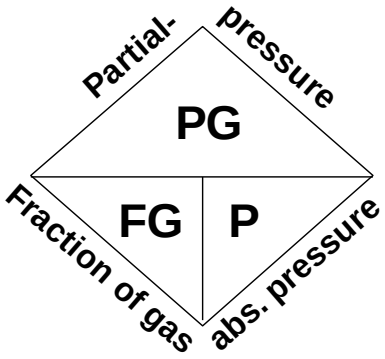
PG = FG x P

Example:
What partial pressure of oxygen occurs in air at 40m depth (5 bar absolute)?

PG = 0.21 x 5 = **1.05 bar**

This equation can be applied in the same way to nitrogen or other gases such as carbon dioxide.

Dalton's DIAMOND



The so-called Dalton's Diamond simplifies finding the solution to the following questions:

1.) How do I find the best mix for a given depth and given ppO_2?
By calculating **FG**!

⇒ **PG = FG x P Partial pressure = fraction of gas x absolute pressure**

2.) How do I find my MOD?
By calculating **P** for a given ppO_2 level!

⇒ **P = Pg / Fg Absolute pressure = Partial pressure / fraction of gas**

3.) How do I determine my O_2-exposure limits?
By calculating **ppO_2**!

⇒ **PG = FG x P Partial pressure = fraction of gas x absolute pressure**

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1.)
Calculating the best mix:

To establish the best mix we must once again decide on the maximum acceptable ppO_2 level. Then we need the planned maximum depth.

Example:
A diver plans to dive to 20m and decides that a max. ppO_2 of 1.3 bar is acceptable. What % of oxygen can be mixed?
We start with the equation

$$FO_2 = \left(\frac{ppO_2}{P} \right)$$

Once again P is replaced by the dive depth. The equation now appears as follows:

$$FO_2 = \left(\frac{ppO_2 \text{ x } 10}{D + 10} \right)$$

$$FO_2 = \left(\frac{1.3 \text{ bar x } 10}{20 \text{ m} + 10} \right) = 0.43 = \underline{43 \% O_2}$$

(Here one would use a 40% nozzle)

2.)
Calculating the oxygen depth limit
A decision has to be made as to what is an acceptable maximum ppO_2 during the dive. For a given mix, the MOD will vary depending on this decision. For OC diving a max. ppO_2 of 1.4 bar is universally accepted as safe. A number of technical diving organisations allow 1.6 bar as the absolute limit. For a rebreather diver whose overall ppO_2 exposure is always high in comparison to the OC diver, a maximum ppO_2 of 1.3 bar should be considered. Furthermore the nature of the dive in terms of stress (such as cold and limited visibility), exertion level and the fitness of the diver on the day will influence his susceptibility to CNS poisoning.

We start with the equation:

$$P = \frac{pO_2}{FO_2}$$

To deduce the MOD we replace the absolute pressure P with the dive depth. The equation now appears as

$$MOD = \left(\frac{ppO_2}{FO_2} - 1 \right) \text{x } 10$$

Example:
A diver with a nitrox 40 mix does not want to exceed a ppO_2 of 1.2 bar. What is the MOD?

$$MOD = \left(\frac{1.2}{0.4} - 1 \right) \text{x } 10 = \underline{20 \text{ m}}$$

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3.)

Calculating the O_2-exposure limits:

Here we need to take into account the CNS exposure tables (see **Table 6** page 38) for Oxygen limits for the central nervous system.

As described in **module D12** we must not exceed established limits for either the level or duration of exposure to raised ppO_2. Here we rely on the 1990 published tables from the National Oceanic and Atmospheric Administration (NOAA).

NOAA Oxygen Partial Pressure and Exposure Time Limits for Nitrogen - Oxygen Mixed Gas Dives				
pO_2	O_2 Single Exposure		24 Hour Total Exposure	
bar	min.	hr	min.	hr
1.6	45	.75	150	2.5
1.5	120	2.0	180	3.0
1.4	150	2.5	180	3.0
1.3	180	3.0	210	3.5
1.2	210	3.5	240	4.0
1.1	240	4.0	270	4.5
1.0	300	5.0	300	5.0
0.9	360	6.0	360	6.0
0.8	450	7.5	450	7.5
0.7	570	9.5	570	9.5
0.6	720	12.0	720	12.0

Table 5

Example 1:
We plan a dive to 29m with a nitrox 32 mix. What is the maximum ppO_2 during this dive?

Before we can use Dalton’s Diamond we must first establish the absolute pressure at 29m.

$$\mathbf{P} = \left(\frac{\mathbf{D}}{\mathbf{10}} + \mathbf{1}\right) \qquad = \left(\frac{\mathbf{29\ m}}{\mathbf{10}} + \mathbf{1}\right) = \underline{\mathbf{3.9\ bar}}$$

This can now be used in the equation PG = FG x P

PG = 0.32 % O_2 x 3.9 bar = **ppO_2 = 1.25 bar**

This value (as usual with dive tables) is rounded-up **on the conservative side** and in this case a value **of 1.3 bar** is used in conjunction with the NOAA tables to establish a maximum exposure time of 180 mins. This should not be confused with no-stop time which is still determined by the nitrogen absorbed. In this case we would reach our no-stop limit after 30 minutes at 29m.

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The above two-step calculation can also be expressed in a single equation:

$$\mathbf{ppO_2 = FO_2 \times \left(\frac{depth}{10} + 1 \right)}$$

To simplify the use of the CNS-limits it is possible to express the amount of exposure during a dive in terms of percentage.

Example 2:
We plan a dive to 18 m with a dive time of 60 minutes. We use a Nitrox 40 premix. *How high is our CNS-loading?*

Once again we start by calculating the ppO_2: **Pg = Fg x P**

$ppO_2 = 0.40 \times 2.8 =$ 1.12 bar

With this value we can read-off the oxygen loading in the CNS-table 6 ($^{\%}/_{min}$) below. To err on the side of safety we round-up if the exact ppO_2 value is not given. This gives a:

CNS-loading at 1.15 bar = 0.44% per minute

We now multiply this value with the dive time to establish the total loading. An ascent time, using an ascent rate of 10m/min, is also included.

CNS_{total} = 60 min + 2 min = 62 min X 0.44 $^{\%}/_{min}$ = 27.28% (rounded) = 28%

CNS % and OTU Values

CNS %- and OTU-values for the given partial pressure of oxygen per minute

ppO_2	CNS-exposure limit Maximum (in min)	CNS % (Per min.)	OTU (Per min.)	ppO_2	CNS-exposure limit Maximum (in min)	CNS % (Per min.)	OTU (Per min.)
0.60	720	0.14	0.26	**1.15**	227	**0.44**	1.24
0.70	570	0.18	0.47	1.20	210	0.47	1.32
0.75	500	0.20	0.56	1.25	196	0.51	1.40
0.80	450	0.22	0.65	1.30	180	0.56	1.48
0.85	400	0.25	0.74	1.35	164	0.61	1.55
0.90	360	0.28	0.83	1.40	150	0.65	1.63
0.95	333	0.30	0.92	1.45	139	0.72	1.70
1.00	300	0.33	1.00	1.50	120	0.83	1.78
1.05	270	0.37	1.08	1.55	90	1.11	1.85
1.10	240	0.42	1.16	1.60	45	2.22	1.92

Table 6

Example 3: ***Multilevel-dive***
The CNS limit at a ppO_2 of 1.6 bar is, according to **Table 5***, 45 mins.*
But what is the limit when I only spend 20 minutes at 1.6 bar but a further 50 minutes at 1.4 bar?

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In this case we calculate the two parts of the dive as separate % values and then add these together.

1.6 bar ≅ 45 min. ≅ 100% / 1.4 bar ≅ 150 min. ≅ 100%

⇒ 20 min.	(20/45)	x	100	=	44,4%
⇒ 50 min.	(50/154)	x	100	=	32.5%
gives:	44.4%	+	32.5%	=	**76.9%**

By this multilevel dive we would reach 77% of our CNS limit.
In **Table 6** the CNS-loading is expressed in $^{\%}/_{min}$, in order to make the calculation of total CNS exposure easier.

Dive time x CNS-Factor $^{\%}/_{min}$ gives the total CNS-loading.

For a repetitive dive the 24 hour exposure limits must be observed. However during a surface interval a recovery factor can be taken into account. This recovery factor is still very much a "rule of thumb" calculation. Generally accepted is a halving of the exposure % for every 90 minutes interval time.

- E.g. A 60% exposure level sinks to 30% after 90 mins. and to 15% after a further 90 mins.

To calculate our CNS_{Rest}-loading for repetitive dives (this is added to the loading of the next dive) we use the **CNS half-life factors** listed in **Table 7**. These show, depending on the length of the surface interval, the percentual reduction of the oxygen loading.

CNS – Half-life Factors						
Interval Time: in hrs.	0:30	1:00	1:30	2:00	2:30	3:00
HL-Factor: x CNS %	0.80	0.63	0.50	0.40	0.31	0.25
Interval Time: in hrs.	3:30	4:00	4:30	5:00	6:00	9:00
HL-Factor: x CNS %	0.20	0.16	0.13	0.10	0.06	0.01

Table 7

Example: Repetitive dive
Following our dive in example 2, we make a surface interval (SI) of 2 hrs. and then a further dive to 15m depth with a dive time of 45 min. Once again we use a Nitrox 40 mix. How high is the residual CNS-loading?

Calculate the new CNS-loading prior to the next dive and also the total loading following the dive:

Solutions: 2:00 hrs. SI result according to **table 7** in a HL-factor of 0.40

CNS_{Rest}	= 28% x 0.40	= <u>11.2%</u>
P in 15 m	= 2.5 bar	
ppO_2	= Fg x P = 0.40 x 2.5 bar	= 1 bar (from **Table 6)** = 0.33%
CNS_{New}	= (45+2) = 47 min x 0.33%	= <u>15.51%</u>
CNS_{total}	= 11.2% + 15.51%	= <u>26.71%</u>

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Calculating the equivalent air depth

To establish no-stop times for any mix a simple calculation can be applied to the use of normal air tables. As the no-stop time is determined by the level of nitrogen that is absorbed during the dive and a raised level of oxygen in the mix correspondingly reduces the nitrogen content, the amount of nitrogen absorbed with a nitrox mix is as though the dive would take place at a shallower depth. This depth, where air would have the same pN_2 as the nitrox mix used, can be calculated. This is referred to as the **E**quivalent **A**ir **D**epth (EAD).

With this calculated EAD the no-stop times from normal dive tables can be utilised.

$$\mathbf{EAD} = \left(\frac{\mathbf{FN_2 \times (D + 10)}}{\mathbf{0.79}} \right) - \mathbf{10}$$

(See the EAD-**Table 8** page 41)

The nitrogen content (FN_2) can either be read from the table or calculated with the aid of the **SCR-Formula** (See page 64).

Example:
A diver with a nitrox 40 mix (60% nitrogen) dives to 20m. What is the equivalent air depth?

$$\mathbf{EAD} = \left(\frac{\mathbf{0.60 \times (20\,m + 10)}}{\mathbf{0.79}} \right) - \mathbf{10} = \underline{\mathbf{12{,}8\,m}}$$

With an equivalent air depth of 13m and the help of an air dive table we can assess that a no-stop time of approx. 50 mins when using air is extended to around 100 mins. (The air no-stop limit at 13m) when using a nitrox 40 mix.

The above referred to calculations are an intrinsic part of nitrox dive planning and need to be carried out carefully and conservatively to be able to enjoy the benefits of nitrox safely.

Calculating the OTU exposure

A further limiting factor is pulmonary toxicity and here the level of exposure is tracked through so-called OTU’s (oxygen toxicity units). One unit represents 1 min of 100% O_2 at atmospheric pressure. Exposure builds up slowly over a number of days and is seldom significant for an OC diver but may well be a significant factor for rebreather divers using units, particularly fully-closed models that expose the user to high levels of ppO_2 over longer periods of time. The following equation applies:

⇒ **1 OTU = 1 Min. of 100% O_2 at 1 bar**

Applied to a dive, this formula is difficult to deal with without using a pocket calculator. Therefore it is easier to use the following **Table 9**.

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EAD Table								
Depth (in m)	32% O_2		40% O_2		50% O_2		60 % O_2	
	EAD	ppO_2	EAD	ppO_2	EAD	ppO_2	EAD	ppO_2
6	4.0	0.50	2.2	0.64	0.1	0.80	- 1.9	0.96
10	7.5	0.62	5.2	0.70	2.7	1.00	0.1	1.20
12	9.2	0.68	6.7	0.88	3.8	1.10	1.1	1.32
14	11.0	0.74	8.2	0.96	5.2	1.20	2.2	1.44
16	12.7	0.81	9.7	1.04	6.5	1.30	3.2	1.56
18	14.5	0.87	11.3	1.12	7.7	1.40	4.2	1.68
20	16.2	0.93	12.8	1.20	9.0	1.50	5.2	1.80
22	17.4	0.99	14.3	1.28	10.3	1.60	6.2	1.92
24	19.7	1.05	15.8	1.36	11.5	1.70	7.2	2.04
26	21.4	1.12	17.3	1.44	12.8	1.80	8.2	2.16
28	23.2	1.18	18.9	1.52	14.1	1.90	9.2	2.28
30	24.9	1.24	20.4	1.60	15.3	2.00	10.3	2.40
35	29.3	1.40	24.2	1.80	18.5	2.25	12.8	2.70
40	33.7	1.55	28.0	2.00	21.6	2.50	15.3	3.00
42	35.4	1.61	29.5	2.08	22.9	2.60	16.3	3.12

Table 8

OTU-table for multiple dives

Days	OTU's / Days	Total	Days	OTU's / Days	Total
1	800	800	9	330	2970
2	700	1400	10	310	3100
3	650	1950	11	300	3300
4	525	2100	12	300	3600
5	460	2300	13	300	3900
6	420	2520	14	300	4200
7	380	2660	15	300	/
8	350	2800	20	300	/

Table 9

Statistically, an OTU exposure of 1450 units inhibits lung function by 10% in 50% of divers. A recompression chamber treatment would expose the diver to around 650 OTU's. On the basis that a chamber treatment could be necessary after any dive the necessary OTU’s are held in reserve and deducted from the daily limit.
Thus: 1450 –650 = **800 OTU’s.** Because the effects accumulate slowly and recovery is also very slow, repetitive days of diving yield a reducing daily tolerance. (See table 9)

Self-assessment quiz

D18 1. Sketch Dalton’s Diamond?
D18 2. What does PG, FG and P stand for?
D18 3. What is the equation for best mix for a given depth?
D18 4. What are the equations for MOD and EAD?
D18 5. List 4 parameters that need to be considered on all nitrox dives.

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Part II Unit Specific Theory

Module E Construction and assembly of the Submatix 100 ST

At the end of this module you should understand the principles of how the Submatix 100 ST works and be able to list its construction elements.

Assembly of the Submatix 100 ST rebreather

The Submatix Rebreather is a gas-recycling unit designed for recreational divers, conceived and built by Uwe Lessmann, himself a diving instructor, between the years 2001 and 2004. With incredible determination, Uwe worked constantly to further improve his early prototypes with, at first, the simple aim of producing a better unit for his own use.

Through resolute development and an open-minded approach to new technologies, a compact, easy to handle rebreather has been developed. Early in 2004 the unit passed the standards required to gain CE-norm approval and since then it has been generally available to the international recreational diving market. Uwe personally invested uncountable hours and test dives in the development; constantly searching to improve the functional, user-friendly and safety aspects of the equipment. Ultimately he has been rewarded with success. The resultant production model is a constant flow, semi-closed rebreather ideally suited to the demands of the recreational diver.

The following diagram shows the primary components of the Submatix SCR 100 ST:

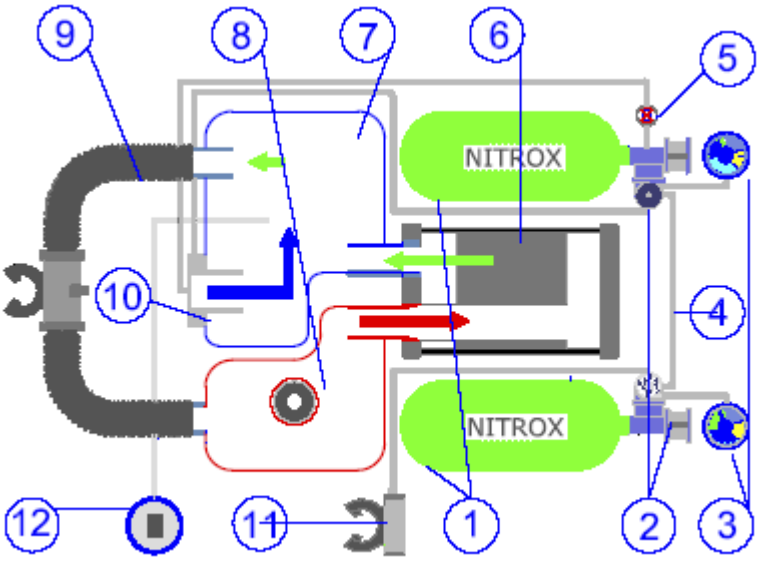

Fig. 5

1	Nitrox tanks	7	Inhale counterlung
2	Nitrox pressure reducing valves	8	Exhale counterlung with over pressure valve
3	Pressure gauges	9	Breathing hose set with turn/slide mouthpiece
4	Low-pressure bridge	10	Bypass valve
5	Constant flow nozzle	11	Bail-out regulator
6	Absorber canister	12	Oxyscan ppO_2 monitor (optional)

In the following module, the individual components will be addressed in detail.

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Module E1 Components of the breathing loop

The breathing loop of a semi-closed rebreather consists of the following components:

- The mouthpiece and inhale/exhale hoses
- The counterlungs, one exhale and one inhale bag
- An overpressure valve set in the counterlungs
- The absorber canister
- The fresh gas supply

The Submatix SCR 100 ST is a mixed gas rebreather with closed breathing loop. The diver inhales fresh gas from the inhale lung (7) via the mouthpiece (9). Exhaled gas flows through the exhale hose to the exhale counterlung (8). From here the gas flows to the absorber canister (6) where Spherasorb removes the CO_2 from the used gas. The cleaned gas flows back into the inhale counterlung (7). Surplus gas is expelled from the loop via the adjustable overpressure valve.

The mouthpiece with inhale and exhale hoses

The rotating barrel mouthpiece can be closed (with the help of the white lever) and is directly connected to the breathing hoses. Mouthpieces which can be opened or closed with just one hand, as with the ST100 mouthpiece, are preferable.

The breathing hoses are made from a flexible, convoluted material that is resistant to kinking when turning the head or sticking together should a negative pressure arise (vacuum).

Photo shows exhale hose and flow-valve (left) and inhale hose and valve (right)

The non-return valves situated on the left and right hand side of the mouthpiece guarantee a one-way gas circulation flow. The valves, similar to the exhale membranes in a regulator second stage, mostly consist of rubber or silicon and should be renewed periodically to ensure a good seal.

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The exhale hose is connected directly to the exhale counterlung and the inhale hose runs from the inhale counterlung back to the mouthpiece. To avoid incorrect assembly the connections are colour-coded and have differing thread sizes

Green ring denotes:
Fresh gas hose from inhale counterlung

Red ring denotes:
Exhaled gas from mouthpiece to exhale counterlung

The SUBMATIX rotating barrel mouthpiece can be operated with a single hand. The barrel has no security rings and is self-sealing due to its eccentric construction. Due to this construction, Submatix has succeeded in putting a mouthpiece at the diver’s disposal which is easy to use and simple to maintain.

Non-return valves situated in the mouthpiece of the Submatix SCR ensure the correct flow of gas through the breathing loop.

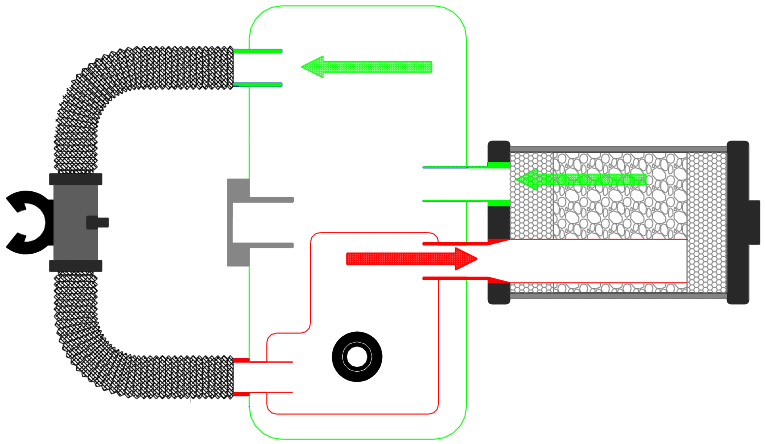

Fig. 6

Through their design, the re-inhalation of expired gas prior to filtration of the CO_2 content is made impossible. However, these membranes should be regularly inspected to ensure their serviceability. A small tear, improper seating, dirt under the seal or simply deterioration with age could all result in the non-return valve failing with the associated risk of hypercapnia.

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Before mounting the plug-in connectors you have to ensure that the corresponding O-rings are in good condition and correctly seated. When assembling, the locking mechanism must snap in. The connection can be checked by tugging lightly.

Note!
The connections are colour-coded (RED – used gas; GREEN – fresh gas). To avoid incorrect assembly ensure that the colours match!

The Submatix developed and patented Pro- Con connectors are simple to use:

Simply push together until the safety ring closes.

NOTE: The safety ring should make an audible click when engaging!!

The rings are colour-coded and the matching of colours should be carefully observed by assembly

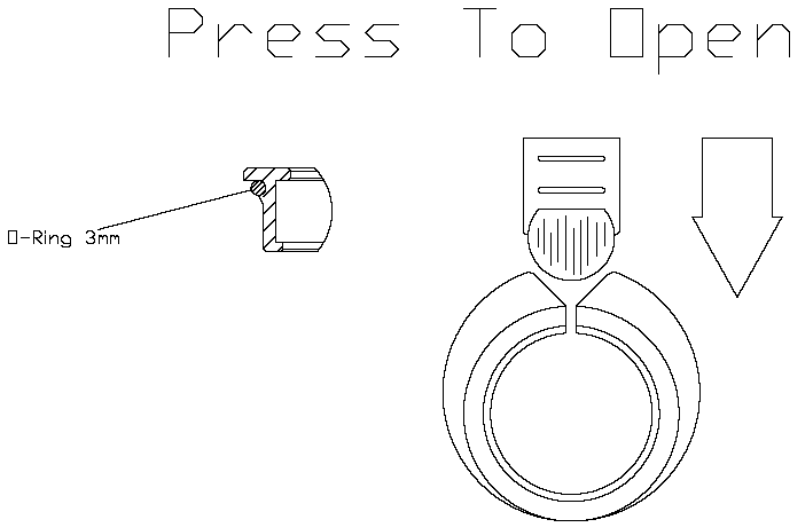

Fig. 7 Pro –Con connector

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In addition to paying attention to the correct flow direction of the breathing hoses you also need to ensure that the mouthpiece sits in a comfortable position.

Completely assembled unit with ADV jacket

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The counterlungs

Carbon dioxide rich gas collects in the exhale counterlung, before either being routed through the absorber canister or vented from the loop via the over pressure valve. The OPV is usually positioned in the exhale counterlung so that only “expended“carbon dioxide rich exhaled gas is lost from the system. With the Submatix SCR 100 rebreather the OPV is located at the back of the diver, a design that allows optimum venting in almost every normal body attitude under water. Such venting will be necessary during ascent due to the increase in counterlung volume as the ambient pressure falls.

Counterlungs (earlier models)

Filtered gas flows from the absorber canister into the inhale counterlung where it mixes with the fresh oxygen rich gas coming from the constant flow supply before being re-inhaled by the diver. Generally, one or more sensors are positioned in the inhale lung to monitor the breathing gas.

A special aspect of the design of the original Submatix counterlungs is the co-axial construction. The exhale counterlung is located within the inhale counterlung which helps to reduce the WOB noticeably, making breathing from the unit more comfortable.

The counterlungs and the over pressure valve (OPV)

Counterlungs (new version)

Plastic spirals are fitted into the counterlungs to prevent them from collapsing fully and thereby hindering gas flow. In terms of volume, the significantly smaller exhale counterlung is fitted immediately in front of the absorber canister. The exhaled carbon dioxide-rich breathing gas that is collected here can, in the case of an overpressure situation– such as

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the expansion of gas on ascent- be vented via the user-adjustable over pressure valve. In this way, rather than the fresh, oxygen rich gas, only the “low-grade“, used gas will be lost from the loop. Simultaneously, the OPV serves as a water-trap, as condensed water from the counterlungs will also be expelled when the valve opens.

Via the constant flow supply and the ADV bypass, fresh breathing gas finds its way from the Nitrox cylinders into the inhale counterlung where it mixes with the already present, recycled and via absorber, filtered gas. To ensure a reliable control of the resultant loop mix, Submatix recommends the use of the Oxyscan (oxygen partial pressure monitor), which uses a sensor positioned in the inhale counterlung.

The absorber cartridge

The absorber (scrubber) cartridge contains soda lime, granulate responsible for the processing of the breathing gas by which the chemical absorption of the carbon dioxide takes place. (See **Module D17** page 32). The scrubber cartridge is connected to the loop between the counterlungs in order to ensure that the exhaled gas flows directly from the exhale-lung and through the soda lime before returning to the inhale-counterlung.

The scrubber tank of the Submatix rebreather has a maximum capacity of 1.7 kg of soda lime. It is manufactured from synthetic Plexiglas material, a material chosen for its low thermal conductivity and its transparency. The insulation property hinders the cooling of the soda lime which increases the effectiveness of the absorption process. The transparency is convenient for the post-dive control as it allows you to check for water ingress and for the colour-indicator without needing to disassemble the unit. If using “Spherasorb” the colour of the granulate changes to lilac when exhausted. However it is important to remember that this colour shift only remains visible for a relatively short time (around 60 minutes). Beyond this time, the colour vanishes again but the soda lime does not regenerate. Once exhausted it remains exhausted!

Absorbents that can be used

Nowadays there are many suitable absorbents (Divesorb, Sofnolime, Soda Lime, Spherasorb and others), but they all vary slightly in their properties. It is therefore wise to stick to the product(s) recommended by the manufacturer of the rebreather as the unit will usually have been adapted to suit the properties of the chosen chemical. (E.g. grain size, dust formation, effective performance time, heat production etc.)

It is important to take particular care with the absorber. It should always be stored in a sealed container in dry surroundings and never be used for longer than the recommended time. When diving with the Submatix SCR 100 ST it is recommended to use “Spherasorb” absorbent.

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This product allows a maximum dive time, in a water temperature of 15°C, of 180 minutes. The time will however vary depending on actual exertion levels and from variations in water temperature.

When filling the cartridge it is particularly important o ensure (e.g. by tapping the sides) that it is correctly packed as incorrectly filled absorber can result in gas channel formation. In such channels the absorber lining is depleted faster and this can ultimately lead to an unfiltered flow of gas. The result will be an increasing carbon dioxide content within the loop.

It is important to remember that once the absorber is exhausted it cannot be regenerated. Used absorber can only be disposed of. Overstepping the limits in use or re-using exhausted material could prove to be a fatal mistake! (Danger of hypercapnia - see **Module D13**)

Filling the absorber canister

Add absorber until the canister is about half full. Tap the canister lightly a number of times, rotating the canister as you do so.

Then fill the canister until the full-mark is reached. Close the canister and install, checking that the O-rings are clean and correctly seated.

Furthermore the following guidelines should be observed:

- Fill the canister before every dive
- An already filled canister can be stored for up to two days providing that it is sealed.
- Ensure that the filter is clean and porous enough to allow gas to flow freely through it
- Never fill the canister with absorber dust
- Protect a filled canister from excessive temperature
- Always follow the manufacturer’s recommendations. (See **Module E7** page 76)

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The breathing loop (shown with the earlier version of the counterlungs)

While the installation of the breathing bag you have to note that the overpressure valve snaps in correctly in the existing holding device. In case of a canted overpressure valve it is possible that water gets into the breathing loop. The inhale and exhale tubes must be fixed from the outside with 1 ½” screws.

Caustic burns caused by absorbent

Chemical burns can occur if water is allowed to penetrate the absorber canister and no remedial action is taken. Water reacts with the soda lime and forms a caustic foam that, if it finds its way to the mouthpiece of the diver can cause unpleasant burns.

The construction of the loop in the Submatix SCR makes such an occurrence very unlikely, but poor preparation, such as incorrect assembly and the failure to carry out pre-dive pressure tests, or major mistakes by the user underwater could lead to water coming into contact with the absorbent.

A burning sensation in the throat, a soapy taste, sudden coughing spasms or other breathing problems could all be symptomatic of such a “caustic cocktail”. The dive should be terminated immediately and the ascent made with OC bail-out. Afterwards the mouth should be rinsed with fresh water. The inhalation of cortisone sprays can help to prevent more extensive lung damage from occurring. In any event, a doctor should be consulted as a safeguard against consequential injury.

The unit, after thorough rinsing and disinfection and once any leak has been remedied, can be put back into service.

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Further components of the rebreather

The components of the rebreather, which work under ambient pressure are those which come into contact with our breathing cycle. The components that are exposed to high pressure are the gas cylinders that provide the breathing supply, the pressure reducing first stages and also the pressure gauges. The first stages are responsible for reducing the pressure (usually around 200 bar) to a constant middle stage pressure (depending on the type of unit somewhere between 9 and 17 bar above ambient). The intermediate pressure components are responsible for the fresh gas supply, whether manual, constant or via a demand valve.

The Nitrox – cylinders

The gas supply for the dive is carried in dual, 200 bar 2-litre steel cylinders. The basic version of the SCR 100 ST is configured to a Nitrox 50 mix. However, by fitting one of the alternative flow-nozzles other nitrox mixes can be used.

The cylinders are held in place within the housing by Velcro bands. The labels on the cylinders allow more accurate information about the contents to be recorded.

Nitrox cylinder with label - (INT VERSION)

Optionally, 2 further 2 litre cylinders can be attached to the unit.

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The first stage pressure reduction valve

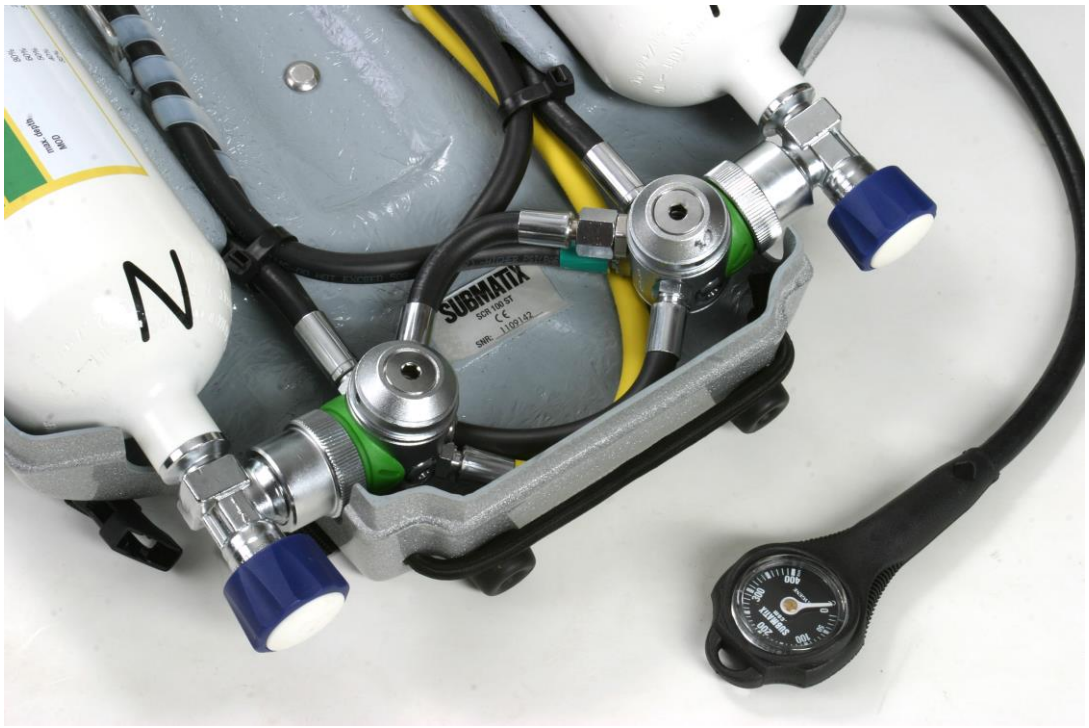
The first stage performs the task of reducing the high pressure in the Nitrox cylinder to an intermediate pressure of (10 bar). Both Nitrox cylinders have their own, separate first stages. The two first stages are linked together by an intermediate pressure connector, in order to ensure a gas supply, should one of the cylinders be empty or the valve closed. In such a situation gas flows from the other cylinder, via the connector, into the intermediate pressure chamber of the deprived first stage.

Additionally both first stages are equipped with separate oxygen compatible manometers (pressure gauges), each displaying the gas content of the respective cylinder.

Attached to the left-hand first stage, there is also a demand valve that is solely for the purpose of supplying an OC bail-out alternative breathing source! Depending on the planned depth, it may also be necessary to carry a further Bail-Out supply.

The first stages are also equipped with intermediate pressure ports for BCD and drysuit inflators. When connecting these, it should be remembered that gas will come direct from the Nitrox cylinder and that if mixes richer than 40% oxygen are used this will require that the inflator valves and hoses be kept in oxygen service.

From the right-hand first stage a hose feeds the bypass-valve regulator that supplies a constant gas flow to the inhale counterlung.



The pressure reducing first stages and pressure gauge

The pressure gauges

The pressure gauges allow the contents of the nitrox cylinders to be monitored. As a rebreather diver will not immediately notice when his gas supply is exhausted, it is essential to monitor the gauges regularly. Every user of an SCR 100 ST should be acutely aware that an absence of a continuous supply of fresh gas could, in the worst case, lead to hypoxia (oxygen starvation)!

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The housing

The ergonomically formed, lightweight GFK - housing of the Submatix SCR provides ideal comfort for the user.

A buoyancy compensator, such as a Jacket or wing, can be fixed to the base-plate of the housing. In accordance with manufacturer’s guidelines the protective cover should be mounted and kept closed during the dive.

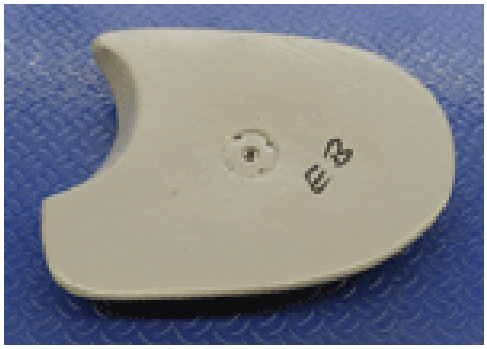
In the housing cover there is a short check list. The points listed, must be checked prior to every dive!

Optional accessories

Weight Harness

See **Module E6** page 75

Trim weight



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Oxyscan – ppO_2 monitor

The Oxyscan 100 Pro can be used to measure oxygen partial pressures. The monitor is activated by contact with water and immediately displays a ppO_2 value.

The monitor is only to a certain extent suited to calculate den Loop pO_2 in a rebreather. Condensation and temperature fluctuations are unavoidable aspects of rebreather diving and both affect the accuracy of the monitor. For these reasons, the monitor should only be used with rebreathers, such as the Submatix SCR, that utilise a known Nitrox premix.

Oxyscan (front view)

If the display shows a reading other than 0.21 when it is first switched on, it must be newly calibrated. In order to do this the PG 7 screw on the rear of the housing must first be removed. Using a screwdriver the unit can be re-calibrated to 0.21 pO_2. Following calibration, the housing should be reclosed. In doing so, ensure that the O-rings are correctly greased and that the thread is not damaged as the screw is tightened.

Note: Avoid HF-radio and Magnet fileds during calibration.

Oxyscan (rear view)

To analyse the contents of the Nitrox cylinders the sensor-head is connected via an adaptor to the cylinder valve. An alternative adaptor enables the Oxyscan to be connected to the BC-Inflator hose.

Technical data:
Submatix SR22 Sensor
Life expectancy:
More than 500000 Vol%h
Battery life: 3 years
Recommended temperature range
5°C-35°C (max. 0°C-45°C)

Sensor replacement: The sensor can be replaced by the user. In order to do this the M32x1.5 screw must first be removed. Then remove the Molex 3–Pin plug. The sensor can now be unscrewed in an anti-clockwise direction. Before fitting the replacement sensor the O-Ring should be removed. Screw the sensor in, finger-tight in a clockwise direction. After the replacement the new sensor will need around an hour or so to “wake-up” before reaching its full output potential.

Sensor storage: Sensors should be stored between temperatures of 5°C to 30°C and never exposed to direct sunlight!

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Module E 2 Gas dosage and constant-flow measurement

At the end of this Module you should be able to identify the correct constant flow nozzle for the Submatix 100 ST and know how to measure the constant flow rate.

The correct choice of constant flow nozzle

ADV with connected flow nozzle

As mentioned in **module D8** for each of the Submatix’s approved Nitrox mixes the appropriate constant flow nozzle must be fitted to ensure an adequate oxygen supply.

The nozzles have colour-coded rings and an O-ring sealed cap. After connecting the nozzle tighten the safety nut by hand.

Constant dosage via the bypass valve

The constant fresh gas dosage, commonly known as the constant flow, is regulated by a needle valve (nozzle) that is designed to allow an exactly calculated quantity of gas to flow through. It is important to know how much oxygen the gas flow contains as this is a major factor in determining the loop oxygen content.

The standard nozzle supplied with the Submatix SCR 100 ST is designed for a Nitrox 50 gas mix and with this mix the unit will always be able to maintain enough oxygen in the loop to be breathable. With this nozzle the fresh gas flow will contain at least 2.5 litres of oxygen per minute and this guarantees a ppO_2 of at least 0.16 bar even with the highest breathing consumption rates. The flow rate can be individually set by using a flow meter or another suitable measuring device. (See **page 58**)

As an option, there is also the possibility of installing other nozzles for use with alternative Nitrox mixes. These are easy to identify through the colour coding that they carry.

The table overleaf shows the available nozzles and the equivalent gas mixes.

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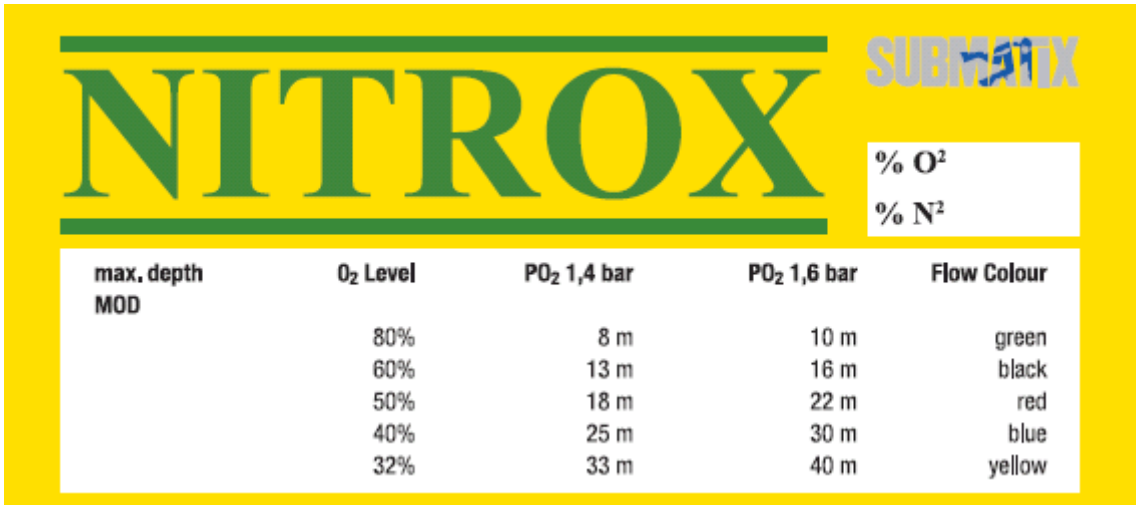
Dosage nozzles and maximum operating depths			
O_2 %	Colour coding	ppO_2 1.4 bar	ppO_2 1.6 bar
80 %	Green	8 m	10 m
60 %	Black	13 m	16 m
50 %	Red	18 m	22 m
40 %	Blue	25 m	30 m
32 %	Yellow	33 m	40 m

Table 10

The unit may only be used with the recommended Nitrox mixes. Failure to observe this guideline puts you at risk of hypoxia or hyperoxia, as either too little or too much loop oxygen may result. The flow nozzles and the corresponded maximum depths are shown on the tank stickers.



The low pressure constant flow hose is marked blue and the low pressure hose of the bypass valve is marked green

Interior view:
ADV bypass connector (green); constant flow connector (blue)

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Checking the constant flow rate

For this measurement use the supplied dosage testing device or another suitable flow meter (correctly calibrated for the gas mix to be measured) and plug it into the bypass valve connector. A Nitrox cylinder with the appropriate mix for the required dosage and at least 50 bar pressure must be connected to the pressure reducing valve. The testing device must stand upright on a flat surface for the duration of the test.

The flow meter should be attached to the exit port of the constant flow nozzle and the flow can be measured providing the cylinder valve is open. The results must be in accordance with the following table:

Tolerances for the constant flow setting		
Gas mix	Minimum flow (L/min)	Maximum flow (L/min)
80 % green	3.3	4.3
60 % black	5.1	6.4
50 % red	6.0	7.95
40 % blue	9.4	11.3
32 % yellow	14.2	16.9

Table 11

Flow meters are available in 3 measurement ranges:

- MMA-21 0-2.5 l/min
- MMA-23 0-10 l/min
- MMA-24 2.5-25 l/min

The gas flow through the meter will now have a particular constant flow volume directly related to the installed dosage nozzle and this moves the floating ball in the meter upwards according to how strong the flow is. From the position of the ball the gas flow can now be read from the scale on the flow meter. To ensure measurement is as accurate as possible the cylinder valve should only be opened very slowly to avoid setting the measuring ball in violent motion.

A further method to check the gas flow is by timing the flow rate. Attach the measuring bag to the bypass valve and ensure it stands on an even surface. Via the over-pressure valve housing breathe the measuring bag empty and then observe it for approx. 20 secs. No leaks should occur- the measuring bag must remain deflated. Then fill the over-pressure valve housing with water up to the full mark.

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Throughout the test, hold the measuring bag upright in the hand. Now open the Nitrox cylinder and simultaneously start to monitor the time. Measure the time it takes before the first bubbles appear in the water-filled over-pressure valve. The measured time must lie within the limits given in **Table 12** page 62.

Before the unit is used it is essential to analyse the gas mixture, to enable possible deviations to be reflected in your dive planning calculations (i.e. EAD).

If a fast descent, raised breathing volume or loss of loop volume (e.g. through mask clearing) creates the need for a fast replenishment of breathing gas, the ADV will automatically open. The loss of pressure in the loop triggers this mechanism in the same way that under-pressure in a regulator second stage (occurring each time an OC diver inhales) causes the membrane to press in against a lever that then deflects inwards and in so doing so opens the valve that lets gas rush in. The constant flow is supplemented and in this way sufficient gas in the loop can always be guaranteed.

Note!
As the mixture in the breathing loop depends on the work of the diver, variations are possible. The correct calculation of the decompression is only possible with a dive computer with oxygen sensors!

If you intend to use such a dive computer ensure that it is compatible with high frequency signals and able to calculate mixes lower than 21%. The optionally available Submatix “Oxyscan A” can be used as a ppO_2-monitor (only for checking as variations may occur through humidity and warmth). The use of suitable CE certified ppO_2 monitors with visual and acoustic warnings is recommended.

Note!
To ensure a trouble-free performance from the constant flow valve, it is necessary to have a minimum reserve of 30 bar in the gas cylinder! Always adhere to this reserve!

Any adjustment or servicing of the bypass valve should always be carried out by a Submatix authorized, factory technician.

Self-assessment quiz

E2 1. With which gas mixes can the Submatix be dived?
E2 2. Which methods can be used to measure the constant-flow rate?
E2 3. Which parameter determines the choice of the dosage nozzle?
E2 4. Why is the choice of the correct nozzle so important?

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Module E 3 Dive Planning

At the end of this module you should be able to conduct a dive plan and calculate all the necessary parameters.

To plan a rebreather dive, where many varying factors each have a decisive influence, demands a thorough knowledge of how these factors depend on and influence each other. The following diagram presents an overview of the relationships and should aid your planning procedures.

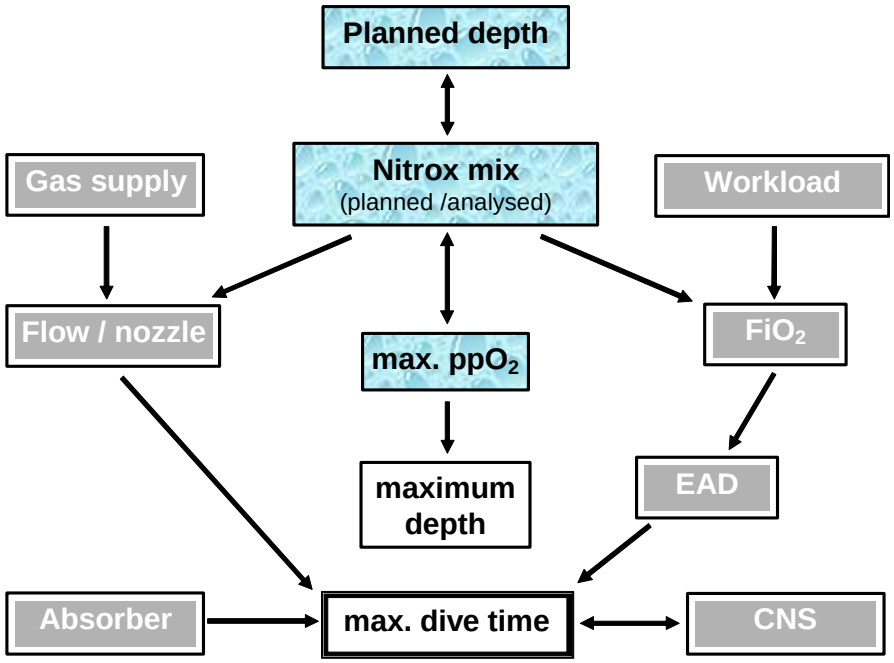

Fig. 8

The initial parameters are shown by the water droplet shaded fields. From these, two will be known and a third can be calculated.
The dark grey shaded parameters all influence the maximum dive time:

1. **Planned depth:** Influences choice of the Nitrox mix and CNS-toxicity.
2. **Nitrox mix:** (planned best mix) determines constant flow, MOD and also the CNS-toxicity.
3. **Max. pO_2:** determines absolute maximum depth (MOD) and CNS-toxicity.
4. **Gas supply:** Determines the maximum possible dive time for the unit.
5. **Flow-nozzle:** Correct dosage ensures the optimum oxygen supply. This is suited to the chosen Nitrox mix.
6. **Absorber:** The elapsed time of the absorber influences the maximum dive time.
7. **EAD:** determined by work-load factor or FiO_2 calculation.
8. **CNS:** Dive time and /or residual loading from previous dives.

The maximum dive time is governed by one or more of the following factors:
Gas supply (calculated from cylinder size, its total fill minus 30 bar safety reserve and the chosen dosage nozzle) ***No-stop time*** according to EAD, ***CNS*** and ***Absorber*** elapsed time

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To commence the dive plan the diver must be clear about the maximum **depth** that he wants to reach during the dive. Based on this decision the best **Nitrox mix** can be filled. Subsequently the correct **dosage nozzle** for the prepared mix can be fitted. From the tables the correct constant-flow rate can then be determined and in turn the maximum available dive time for the given total gas supply. In relation to this the **elapsed time of the absorber** must be taken into account. Finally the **no-stop time** can be read from the Nitrox tables. Alternatively with the aid of the SCR - Formula the EAD can be calculated and the no-stop time can be read from standard air tables.

Diving with the Submatix SCR 100 ST

The following factors need to be considered when planning a dive:

1. Max. operating depth MOD
2. Best MIX
3. Max. ppO_2
4. Constant flow nozzle
5. Absorber Elapsed time
6. Gas supply
7. EAD and no-stop limits
8. CNS - loading

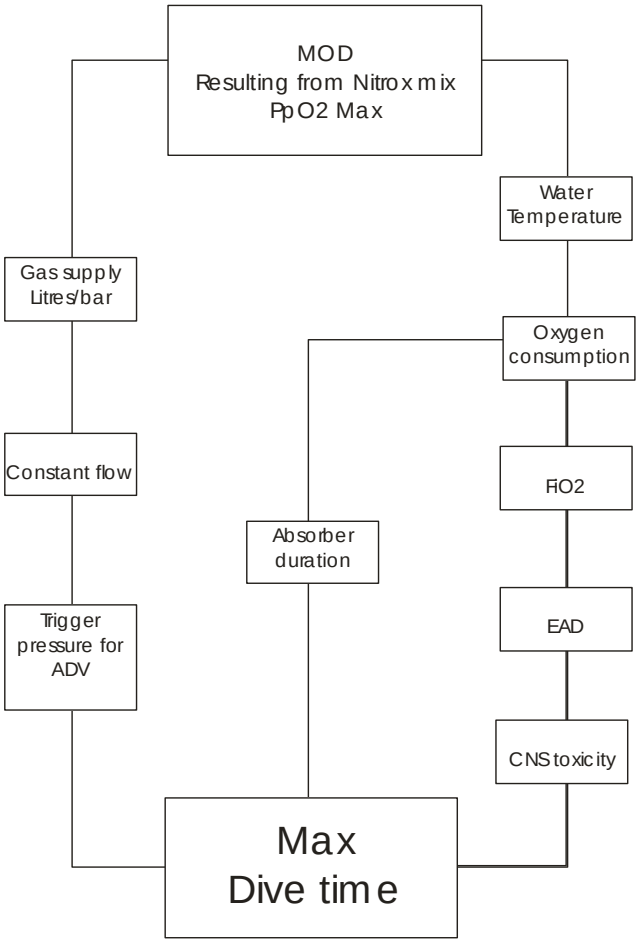

Fig. 9

To commence the dive plan the diver must be clear about the maximum **depth** that he wants to reach during the dive. Based on this decision the best **Nitrox mix** can be filled. Subsequently the correct **dosage nozzle** for the prepared mix can be fitted according to the table overleaf.

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The choice of constant flow nozzle determines the maximum flow times:

Nitrox mix	Dosage l/min	Flow rate	loop mix	Max. duration of the constant dosage 4lt / 200 bar Res 30 bar	Max. duration of the constant dosage 4 lt / 300 bar Res 30 bar
	0.75	3.0	73 % O_2	226 min	339 min
80 % O_2	1.25	3.0	66 % O_2	226 min	339 min
	2.25	3.0	20 % O_2	226 min	339 min
	0.75	5.0	53 % O_2	135 min	204 min
60 % O_2	1.25	5.0	47 % O_2	135 min	204 min
	2.25	5.0	27 % O_2	135 min	204 min
	0.75	6.0	43 % O_2	113 min	156 min
50 % O_2	1.25	6.0	37 % O_2	113 min	156 min
	2.25	6.0	20 % O_2	113 min	156 min
	0.75	10	35 % O_2	68 min	102 min
40 % O_2	1.25	10	31 % O_2	68 min	102 min
	2.25	10	23 % O_2	68 min	102 min
	0.75	15	38 % O_2	45 min	67 min
32 % O_2	1.25	15	26 % O_2	45 min	67 min
	2.25	15	20 % O_2	45 min	67 min

Table 12

The following maximum depths apply:

Constant flow dosage nozzles and maximum operating depth(MOD)			
O_2 %	Colour coding	ppO_2 1.4 bar	ppO_2 1.6 bar
80 %	Green	8 m	10 m
60 %	Black	13 m	16 m
50 %	Red	18 m	22 m
40 %	Blue	25 m	30 m
32 %	Yellow	33 m	40 m

Table 10

A decisive factor with semi-closed rebreathers is the percentage value of **actual inhaled O_2** (FiO_2).
There are two reasons for this:

1. The FiO_2 may not under any circumstance drop below 16%, as otherwise the onset of hypoxia cannot be excluded.

2. Below 21%, the Nitrox mix will have an equivalent air depth (EAD) deeper than with air itself – resulting in higher narcosis and decompression factors.

The aim is to find a compromise between too high a constant flow (Vs = supply flow) and one that is too low. Loop FiO_2 should be as close to the O_2 content of the Nitrox mix as possible. This ensures that gas consumption/wastage is as low as possible.

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Calculation of the FiO_2 (loop O_2-content)

The calculation of the FiO_2 can never be accurately determined in advance of the dive as this value is influenced by many variable factors. Therefore, when planning a dive, it is usual to start with known or general figures to establish an approximate value.

To calculate the FiO_2 value as accurately as possible, we use a model that assumes that the diver remains at a constant depth and has a constant work-load factor. This enables us to use the **semi-closed rebreather (SCR) formula**.

The **FiO_2** is determined by the following values:

- Oxygen content of the Nitrox mix **(FsO_2)**
- The volume of the fresh gas flow **(Vs)**
  (Together these two determine the quantity of oxygen delivered)
- Oxygen consumption rate of the diver **(VO_2)**

Volume of the fresh gas flow = residual gas volume + used gas volume

$Vs = Qv + VO_2$

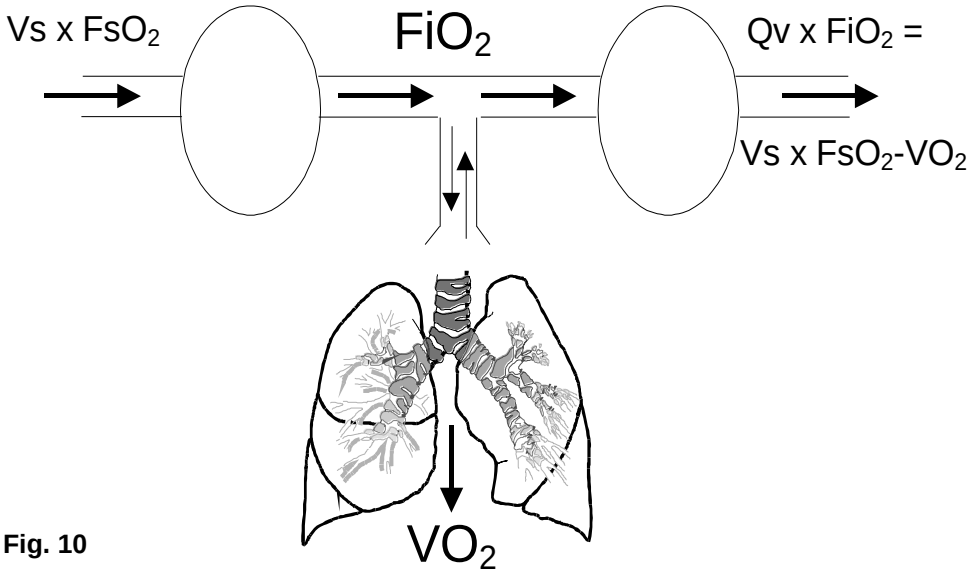

Fig. 10

In this constant model the oxygen addition and the oxygen loss (overpressure valve **(Qv)** + diver’s oxygen consumption **(VO_2)**) are identical and this means that the loop oxygen level remains constant.

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Applying the same to the oxygen content:

$$\mathbf{Vs \times FsO_2 = Qv \times FiO_2 + VO_2}$$

Due to the constant flow of gas to the loop, some of the oxygen not consumed by the diver will be vented via the over-pressure valve.

As Vs und VO_2 are known values, Qv can be replaced by them.

$$\mathbf{Vs \times FsO_2 = (Vs - VO_2) \times FiO_2 + VO_2}$$

The SCR - Formula

With the aid of this formula it is possible to calculate the reduced O_2-content in the loop. Due to oxygen consumption this will always be lower than the oxygen level in the carried gas cylinder.

$$\mathbf{FiO_2} = \frac{(\mathbf{Vs \times FsO_2}) - \mathbf{VO_2}}{(\mathbf{Vs} - \mathbf{VO_2})}$$

FiO_2	=	Fraction of inhaled oxygen
Vs	=	Volume of the gas flow in L/min
FsO_2	=	O_2-content in the Nitrox mix
VO_2	=	Volume of oxygen consumed in L/min

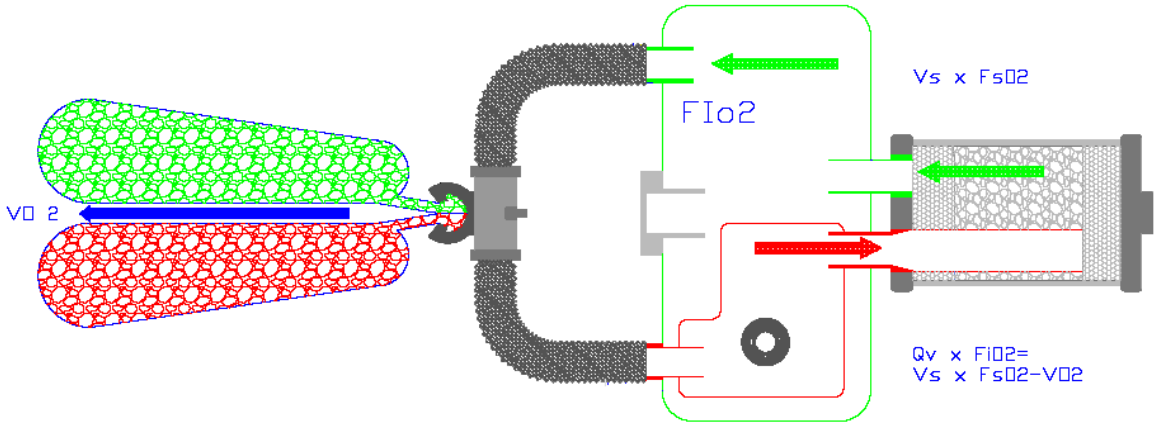

Fig. 11

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Example: How high is the loop oxygen content, given a Nitrox 32 gas supply; a chosen flow rate of 15.0 l/min and a high work-load on the diver resulting in an oxygen consumption level of 2 L/min?

Given: FsO_2 = 0.32
Vs = 15.0 l/min
VO_2 = 2.0 l/min

$$\mathbf{FiO_2 = \frac{(15.0 \text{ x } 0.32) - 2}{(15.0 - 2)} = 0.215 = \underline{22\% O_2}}$$

In this scenario the diver would breathe an almost air-like gas with 22% O_2 content.
Thereby we find that this combination of Nitrox mix, flow rate and high oxygen consumption still guarantees sufficient oxygen even in shallow water.

Consider what would happen if we were to use compressed air (21% O_2) under the same circumstances:

FsO_2 = 0.21
Vs = 15.0 l/min
VO_2 = 2.0 l/min

$$\mathbf{FiO_2 = \frac{(15.0 \text{ x } 0.21) - 2}{(15.0 - 2)} = 0.09 = \underline{9.0\ \% O_2}}$$

Note: In shallow water this would be an absolutely hypoxic mix!!!!

The FiO_2, calculated through the SCR - Formula, is needed for dive planning. In the plan shown we can see that this FiO_2 value is used for our EAD calculation. Thereby we always assume a VO_2 of 2.5 l/min, which represents a very high load. In so doing we will always remain on the conservative side with the calculation of our no-stop time.

Example:

How high is the oxygen concentration in the loop if, using a Nitrox 50 % premix and with a constant flow setting of 6.5 l/min, the diver has an oxygen consumption rate 1.5 l/min?

$$FiO_2 = \frac{(VsxFO2) - VO2}{(Vs - VO2)}$$

$$FiO_2 = \mathbf{\frac{(6.5x0.5) - 1.5}{(6.5 - 1.5)}}$$

FiO_2 = 0.35 or 35 % O_2

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What happens however, if the oxygen consumption climbs to 2.5 l/min?

$$FiO_2 = \frac{\mathbf{(6.5x0.5) - 2.5}}{\mathbf{(6.5 - 2.5)}}$$

$FiO_2 = 0.187$ or 18 % O_2

This shows us that even under a heavy work load a Nitrox 50 mix will ensure at least 18% oxygen in the loop.

What FiO_2 results when we mistakenly use a Nitrox 40 mix with the constant flow nozzle designed for a Nitrox 50 mix?

Initially let’s assume that the oxygen consumption rate lies around a normal level of 1.5 l/min:

$$FiO_2 = \frac{\mathbf{(6.5x0.4) - 1.5}}{\mathbf{(6.5 - 1.5)}}$$

$FiO_2 = 0.35$ or 35 %O_2

But what would happen if the exertion level rises to 2.5 l/min?

$$FiO_2 = \frac{\mathbf{(6.5x0.4) - 2.5}}{\mathbf{(6.5 - 2.5)}}$$

$FiO_2 = 0.025$ or less than 3% O_2 = FATAL CONSEQUENCES!!!

The normal consumption lies by most divers, given an average workload, somewhere between 0.6 L/min and 1.25 L/min. However, this level can suddenly climb in a fight against a strong current or when the diver starts shivering from cold. It is therefore very important to always assume the highest possible exertion level and choose the flow nozzle with regard to the chosen mix accordingly.

Even if you always avoid Jo-Jo-profiles and fast ascents, the loss of gas via the OVP should not be forgotten when calculating the constant Flow (Vs). If you choose the correct flow nozzle for your mix this factor has already been taken into account.

The Submatix SCR 100 ST is constructed to ensure that even if the user has an oxygen consumption of 2.5 litres/min there will always be a partial pressure of at least 0.16 bar in the loop.

Note: **Accidents arising through inappropriate use of constant flow nozzles or incorrect choice of Nitrox premix is solely the fault of the user and is not likely to be covered by any insurance!!!**

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Calculating the equivalent air depth (EAD)

To determine the no-stop time for a particular Nitrox mix, it is first necessary to find the equivalent air depth (EAD). With the EAD standard air tables (e.g. Deco 2000) can be used to read–off the no-stop time.

Note! To calculate the EAD always use the % of nitrogen (FiN_2) present in the loop

To determine the value FiN_2 the following table can be used. By assuming that the nitrogen content in the loop gradually climbs above that contained in the supply cylinder (e.g. through diffusion out of body tissues) we will always be on the conservative side when calculating no-stop time.

Nitrox mix	O_2 consumption l/min	Dosage l/min	FiO_2	FiN_2
80 % O_2	0.75	3.0	73 % O_2	27 % N_2
	1.25	3.0	66 % O_2	34 % N_2
	2.25	3.0	20 % O_2	80 % N_2
60 % O_2	0.75	5.0	53 % O_2	47 % N_2
	1.25	5.0	47 % O_2	53 % N_2
	2.25	5.0	27 % O_2	73 % N_2
50 % O_2	0.75	6.0	43 % O_2	57 % N_2
	1.25	6.0	37 % O_2	63 % N_2
	2.25	6.0	20 % O_2	80 % N_2
40 % O_2	0.75	10	35 % O_2	65 % N_2
	1.25	10	31 % O_2	69 % N_2
	2.25	10	23 % O_2	77 % N_2
32 % O_2	0.75	15	38 % O_2	62 % N_2
	1.25	15	26 % O_2	74 % N_2
	2.25	15	20 % O_2	80 % N_2

Table 13

The EAD can be determined using the formula below:

$$EAD = \left(\frac{\mathbf{FiN2x(depth+10)}}{\mathbf{0.79}}\right) - 10$$

Example:

Using 50 % Nitrox, a dive to 20 metres is planned.
The oxygen consumption level is 1.25 l/min.
The EAD can be calculated as follows:

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$$\mathbf{EAD} = \left(\frac{\mathbf{0.63x(20+10)}}{\mathbf{0.79}}\right) - 10 = 13.92 \text{ m}$$

That means that a dive to 20m using Nitrox 50 and with an oxygen consumption level of 1.25 l/min has a no-stop time equivalent to an air dive to 14m.

To simplify these calculations, values from the following table can be used. An oxygen consumption rate of 1.0 l/min is assumed.

EAD Table										
Depth (in m)	32 % O_2		40 % O_2		50 % O_2		60 % O_2		80 % O_2	
	EAD	ppO_2	EAD	ppO_2	EAD	ppO_2	EAD	ppO_2	EAD	ppO_2
6	4.0	0.50	2.2	0.64	0.1	0.80	-1.9	0.96	-5.9	1.28
10	7.5	0.62	5.2	0.70	2.7	1.00	0.1	1.20	-4.9	1.60
12	9.2	0.68	6.7	0.88	3.8	1.10	1.1	1.32	-4.4	1.76
14	11.0	0.74	8.2	0.96	5.2	1.20	2.2	1.44	-3.9	1.92
16	12.7	0.81	9.7	1.04	6.5	1.30	3.2	1.56	-3.4	2.80
18	14.5	0.87	11.3	1.12	7.7	1.40	4.2	1.68	-2.9	2.24
20	16.2	0.93	12.8	1.20	9.0	1.50	5.2	1.80	-2.4	2.40
22	17.4	0.99	14.3	1.28	10.3	1.60	6.2	1.92	-1.8	2.56
24	19.7	1.05	15.8	1.36	11.5	1.70	7.2	2.04	-1.3	2.72
26	21.4	1.12	17.3	1.44	12.8	1.80	8.2	2.16	-0.8	2.88
28	23.2	1.18	18.9	1.52	14.1	1.90	9.2	2.28	-0.3	3.04
30	24.9	1.24	20.4	1,60	15.3	2.00	10.3	2.40	0.12	3.20
35	29.3	1.40	24.2	1.80	18.5	2.25	12.8	2.70	1.3	3.60
40	33.7	1.55	28.0	2.00	21.6	2.50	15.3	3.00	2.6	4.00
42	35.4	1.61	29.5	2.08	22.9	2.60	16.3	3.12	3.2	4.16

Table 14

The normal consumption given an average workload lies, by most divers, somewhere between 0.6 L/min and 1.25 L/min. For more accurate calculation of the EAD the following FiO_2-values can be used. (See **exercise** on page 69)

Oxygen consumption		FiO_2 in relation to O_2-consumption							
		Premix 60%		Premix 50%		Premix 40%		Premix 32%	
workload	**l/Min**	Factor	**FiO_2**	Factor	**FiO_2**	Factor	**FiO_2**	Factor	**FiO_2**
high **h**	**2.5**	0.50	**30%**	0.50	**25%**	0.55	**21%**	0.594	**19%**
g	**2.0**	0.65	**39%**	0.64	**32%**	0.65	**26%**	0.688	**22%**
f	**1.75**	0.716	**43%**	0.70	**35%**	0.70	**28%**	0.719	**23%**
normal **e**	**1.5**	0.766	**46%**	0.76	**37%**	0.75	**30%**	0.781	**25%**
d	**1.25**	0.816	**49%**	0.80	**40%**	0.80	**32%**	0.812	**26%**
c	**1.0**	0.866	**51%**	0.86	**42%**	0.85	**33%**	0.844	**27%**
low **b**	**0.75**	0.90	**54%**	0.90	**44%**	0.875	**35%**	0.906	**28%**
a	**0.5**	0.933	**56%**	0.92	**46%**	0.925	**37%**	0.937	**30%**

Table 15 (the FiO_2values have been rounded-up)

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As shown in **Fig. 8** page 60, we consider 3 initial parameters.

- Planned depth
- Nitrox mix
- Maximum ppO_2

Two of these parameters will also be known.

If we know the maximum required depth, then we can calculate the best mix to reflect our maximum pO_2 of 1.4 bar.
If the Nitrox mix is already fixed (E.g. there is still enough Nitrox 50 in the cylinder following a prior dive) and we wish to maintain a maximum pO_2 of 1.4 bar then aided by Dalton’s diamond it is possible to calculate the maximum depth.
(See **module D18** page 35)

For these, either calculated or pre-determined Nitrox mixes, a manufacturer’s pre-determined dosage nozzle (Vs) must be fitted. This selection, together with the total quantity of gas, determines the maximum possible dive time.
With the help of the SCR-Formula the FiO_2 can be found and aided by the EAD-formula the no-stop time can then be calculated.
Ultimately, although 4 factors influence our maximum dive time, the factor giving the **shortest time** is always the determining factor.

➢ CNS-exposure limit	=	Dependant on pO_2 level
➢ No-stop time	=	Dependant on min. FiO_2 ⇒ EAD
➢ Absorber	=	Full canister: 3 hours
➢ Gas supply	=	Nozzle ⇒ flow rate (Vs)

Exercises:

Given:
Nitrox 40; 2x4l filled to 200 bar (30 bar Res.);
max. ppO_2: 1.4 bar
Exertion level: light
Absorber fill quantity: 1.8 l
Planned depth: 20m

Find:
Gas supply? Flow nozzle?
MOD? ppO_2? EAD? No-stop time?
CNS-limit? Absorber time (new fill)?
Maximum dive time?

Solutions:

- Gas supply: **1360 litres**
- This gives a flow duration in an ideal situation of **130 minutes**
- Flow nozzle: **10.4 l/min**
- $$\mathbf{MOD = \left(\frac{1.4bar}{0.40} - 1\right) x\ 10 = 25m}$$

The ppO_2 at the planned depth can be calculated from Dalton’s formula

- $$\mathbf{pO_2 = 0.40\ x \left(\frac{20}{10} + 1\right) = 1.2\ bar}$$

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EAD calculation:

- O_2-workload factor using Nitrox 40% (See **Table 15**): **b** = **0.875**
- FiO_2 = 40% x 0.875 = **35% O_2** = **65% N_2**
- **EAD =** $\left(\frac{\mathbf{0.65\ x\ (20m + 10)}}{\mathbf{0.79}}\right) - \mathbf{10}$ = **14 m** (rounded-up)
- No-stop time of ≈ **90 minutes**
- CNS-limit for 1.2 bar according to NOAA tables = **213 minutes**
- Absorber time: 2.25 l with an elapsed time of 0:00 hours = **240 minutes**

The maximum dive time is determined by the no-stop time at the EAD:

- **14 m ≈ 89 minutes**

Example: Calculating dive times

The following 4 factors influence the potential dive time:

Gas supply	Gasvorrat and selected flow-nozzle
Absorbent	Minimum of 2 hours for a new filling
No-stop time	dependant on FiN_2 - EAD
CNS – exposure limit	dependant on ppO_2

Example:

We plan a dive in the Red Sea with Nitrox 50.
This gives us an MOD of 18 metres for a max. ppO_2 of 1.4 bar and 22 metres if a ppO_2 of 1.6 bar is acceptable

Our planned maximum depth is 20 metres and accordingly this means that we will be exposed to a ppO_2 of 1.5 bar at that depth.

Using this mix and assuming that the oxygen consumption level is 1.0 l/min, the nitrogen concentration in the loop will be around 60 %.
Our EAD is therefore 12.78m, which we round-up to 13 metres.
Using “Deco 2000” tables we therefore have a maximum no-stop time of 72 min.

According to the NOAA - table the CNS - limit for the dive lies at 120 min.

The available gas supply of 680 litres (30 bar reserve calculated per cylinder) would last for 104 minutes with a constant flow setting of 6.5 l/min.

In this case the maximum possible dive time is determined by the no-stop limit, as we have decided that we do not want to undertake any decompression obligations. Therefore our maximum dive time will be 72 minutes.

Submatix dive planner

As an alternative aide to better dive planning you can also use the Submatix dive planner that is to be found on the accompanying CD.

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Calculating the Required Bail-Out Gas Supply

Although semi-closed rebreathers work very reliably due to their entirely mechanical components and demonstrate very efficient values in regard to the potential dive time, it is still necessary to consider an alternative gas supply to ensure that you carry enough gas to cover emergency situations that could arise for yourself and/or for your buddy. This is usually a familiar “open-circuit” configuration.

Here the decisive factor is the amount of gas necessary to enable a controlled ascent from the maximum depth

- with a maximum ascent rate of **10 metres per minute**

The average gas consumption for an experienced diver usually lies around approx. 10 to 25 litres per minute. If a switch to an alternative gas supply and an ascent under otherwise normal circumstances is involved then,

- **at least 25 Litres per minute** should be calculated.

If the situation causes panic, gas consumption will increase significantly and could reach as much as 90 l/min!!! It is up to each diver individually, to determine his own personal level for the gas calculation. To raise the safety margin we will therefore assume a level for the complete ascent equivalent to a

- gas consumption of **25 l/min at maximum depth!**

To take a further safety factor into account, the ascent should not empty the cylinder entirely. At the end we should have

- a **reserve of 20%** in the cylinder.

Taking the above factors into account we arrive at the following calculation for the bail-out gas quantity.

Given:	**Find the:**
Ascent rate: 10 m/min	Ascent time?
RMV: 25 l/min;	Gas supply in litres incl. a 20% reserve?
Depth: 40 m = 5 bar	Cylinder size?

Solutions:

- Ascent time: $= \frac{\textbf{depth}}{\textbf{ascentrate}} = \frac{\textbf{40 m}}{\textbf{10 m/min}} =$ **4 mins**
- Gas required: = **Gas consumption x ascent time x absolute pressure**
  = **25 l/min x 4 min x 5 bar** = **500 litres**
- 20% reserve: $= \frac{\textbf{Gas supply in litres}}{\textbf{80\%}} \textbf{ x 100\%} = \frac{\textbf{500 l}}{\textbf{80\%}} \textbf{x100\%} =$ **625 litres**
- Cylinder size: $= \frac{\textbf{total gas required}}{\textbf{cylinder pressure}} = \frac{\textbf{625 bar/l}}{\textbf{200 bar}} =$ **3.125 litres**

As can be derived from this example, we need at least a 3 litre cylinder as bailout supply - better still 4 litres, if further gas is to be used for buoyancy compensation or drysuit.

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300 bar cylinders would prove advantageous here, as with the same size cylinder the available gas reserve is increased.

Safe diving with rebreathers demands an adequate bail-out supply! To calculate this requirement the following must be taken into account:

- **Raised respiratory minute volume!**
- **The maximum depth!**
- **The, from the above, resulting gas quantity needed for an emergency ascent to the surface!**
- **The additional gas needed for buoyancy control and for positive buoyancy on the surface following an emergency ascent!**

Beware: never dive with an inadequately filled bail-out cylinder!

Self-assessment quiz

E3 1. What is the MOD for a Nitrox 32 mix?.
E3 2. What is meant by “best mix”?
E3 3. List 3 parameters that must be taken into account when planning Nitrox dives.
E3 4. What is the formula for MOD!
E3 5. Calculate for the following dive:
Gas consumption; max. flow duration, Flow-nozzle; MOD; FiO_2; EAD; no-stop time and CNS-loading.
Given: Nitrox 50 %; 5 litre 200 bar cylinder; Max. ppO_2 1.4 bar; dive time 60 minutes; Max. depth 18 m; O_2-consumption 1litre/min;
E3 6. List 4 parameters that must be taken into account when calculating bailout gas reserves.
E3 7. Calculate the required bailout requirement for an emergency ascent given an RMV of 28 litres, a depth of 30 metres and a 20% reserve for buoyancy requirements.

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Module E 4 Use of Dive Computers

As the oxygen content (pO_2) in the breathing gas fluctuates with the consumption level of the diver, the nitrogen content (pN_2) will also fluctuate accordingly. This fluctuation in pN_2 cannot be registered by a normal Nitrox dive computer. Such computers base their calculations on fixed nitrogen content. Accurate decompression data is based however on the actual nitrogen content (i.e. the nitrogen partial pressure) and the depth. If you wish to use your dive computer you must always assume the maximum oxygen consumption level and accordingly the maximum pN_2 level, to ensure a conservative decompression calculation. An uncritical use of diving computers without regard to the above mentioned facts can lead to false decompression data when diving with rebreathers. To fully gain all of the advantages of SCR-diving -long dive times with shorter, but safe decompression- the actual loop ppO_2 must be continually monitored.

Using Nitrox dive computers without oxygen sensors
Experience has shown that when using normal Nitrox computers the Nitrox mix programmed into the computer should be 10% less than the premix in the cylinder. This ensures that the decompression information reflects real values within acceptable limits. The depth limit must be planned before the dive and the MOD strictly observed. This technique is based upon the assumption that the diver will have an average oxygen consumption level!

Using Nitrox dive computers with oxygen sensors
If a dive computer is used that has its own oxygen sensor, the following tip should be observed:
Some computers only show and calculate oxygen % values of 21% or above, e.g. the UWATEC AirXO_2. If, during use, a lower loop mix occurs, such computers will nonetheless continue to assume a mix containing 21 % for decompression calculations and this could lead to an underestimation of decompression obligations.

Interface for Uwatec Oxy2: a compact interface is available from Submatix that enables easy adaption of the Uwatec Oxy 2 sensor head to fit the housing of the SCR 100 Rebreather. The Sensor can be attached to the counterlung via a Draeger P-Con. Sensor readings and ambient pressure are transmitted via a pneumatic cable.

This construction enables individually adapted cable lengths as well as better protection from moisture. The use of 2 x 2 dual cathode sensors or 1 x dual cathode and SR 22 Sensor is possible. Instructions for installation are available on the service CD.

HF Interference
This is a largely disregarded problem that can affect dive computers that use HF radio waves to transfer data between the oxygen sensor and the computer. Should, for example calibration be taking place just as a nearby mobile phone logs onto a new network or in the proximity to a radio mast, the accuracy of the calibration could be affected. This would lead to a series of false calculations and assumptions by the computer including the actual gas mix%, CNS exposure level, MOD and no-stop time.

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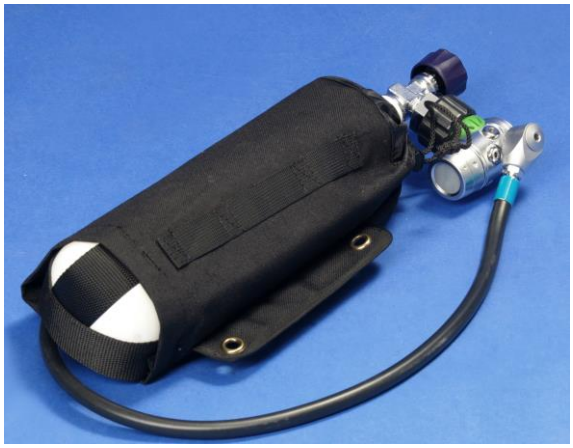
Module E 5 Cylinder Filling

When filling the cylinders it is important that the oxygen content lies within plus/minus 2 % of the fitted constant flow nozzle, otherwise hypoxia, hyperoxia or even decompression sickness threaten.

Directly after filling is completed an oxygen analysis should be undertaken and the result, along with the fill pressure and the date of the fill, should be entered with a waterproof marker on the appropriate label or sticker attached to the cylinder. Do not forget to take into account the fluctuation tolerance when calculating the EAD!

When the diver collects the cylinder he should perform a second analysis of the cylinder contents and countersign the results.

2 x 2 litres nitrox tanks with valves, Nitrox 1st stages, low-pressure bridge and variable constant flow nozzle (blue)



Optional available gas supply

Note: **An inaccurate gas analysis or false calculations can lead to very serious consequences arising!**

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Module E 6 Technical Data

Model:	SCR 100 ST (Semi-closed rebreather)
Gas supply:	2 x 2 litre steel cylinders (optional Aluminium or V4A). Breathing gasses must correspond to the guidelines for medical oxygen (DIN 3188, EN 132)
Operating temp:	+4°C to +34°C
Operating pressures:	200 to 20 bar
Absorbent fill:	approx. 1.7 Kilograms
Counterlungs:	9 litre coaxial design
Housing dimensions:	670 x 390 x 170 mm (without hoses)
Weight:	ca. 14 Kilogram
Buoyancy:	approx. 2.5 Kilogram positive
Flow nozzles:	80% 60% 50% 40% 32%
Norm:	EN/CE
Optional accessories:	Oxyscan 100 Pro Weight harness, buoyancy / rescue collar Flow nozzle for 100% oxygen Trim weights approx. 3Kg Flow meter - 3 available scales: MMA 21 0.5-2.5 l/min, MMA 23 1-10 l/min, MMA 24 2.5-25 l/min

Further technical and service-information can be found on the accompanying manufacturer’s service CD

Every SCR 100 ST can easily be converted to an SCR 100 XT, SCR 100 SMS or emCCR. Thus the SCR 100 ST serves as a base for additions and for future technical developments.

100 XT – The XT can be dived using two differing Nitrox premixes. With this unit the diver can manually switch from one mix to the other using the MPSS switching block (3) developed by Submatix.

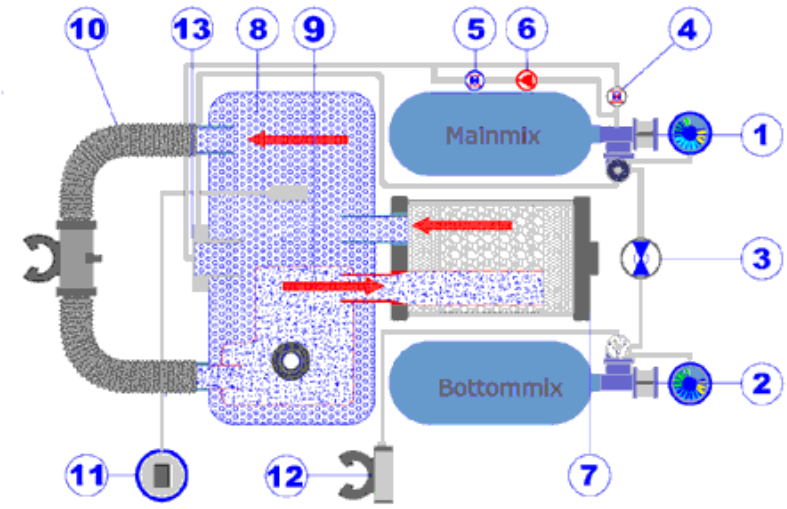

Fig.12

100 SMS – The SMS (self mixing system) is a mechanical self mixing system that can be dived in the range of 0-40m. The system utilises a depth dependent constant flow dosage and offers the diver a Nitrox mix of 28-32% at all times. Further training is necessary to dive with this system. Ask your IART instructor for more information.

emCCR 100 - electronic gas injection to aid the manual control of a chosen setpoint within a closed circuit loop. The Submatix emCCR 100 rebreather is designed for recreational dives to a maximum of 40 metres with Nitrox or for technical Trimix dives to 100 metres. Further training is necessary to dive with this system. Ask your IART instructor for more information.

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Module E 7 Absorption properties of Spherasorb®

Spherasorb® is recommended by Submatix for use with the 100 ST. Its specific properties are listed below.

Duration time of Spherasorb
The Submatix absorber canister has a capacity of 1.8 kg Spherasorb absorbent. The effective duration times are related to the following criteria:

- Water temperature	4 (-2) °C
- RMV	40l/min
- Oxygen consumption	1.78 l/min
- Break-through level	0.5 vol. % CO_2 in inhaled gas
- CO_2 Absorption	1.6 l/min
Resultant effective duration	**135 min**

- Water temperature	4 (-2) °C
- RMV	30l/min
- Oxygen consumption	1.33l/min
- Break-through level	0.5 vol. % CO_2 in inhaled gas
- CO_2 absorption	1.2 l/min
Resultant effective duration	**180 min**

Carbon Dioxide Absorption of SPHERASORB/SOFNOLIME			
CO_2 absorption	CO_2 production	Using time of scrubber at 1.7 kg filling	Water temperature
Sofnolime CD 100 l/min	1.2 l/min	140 min	4°C
	1.6 l/min	105 min	4°C
Spherasorb 120 l/min	1.2 l/min	170 min	4°C
	1.6 l/min	125 min	4°C
Sofnolime 797	1.2 l/min	198 min	4°C
	1.6 l/min	148 min	4°C

Table 16

According to the US Navy manual (edition 4.20.Januar 1999), an oxygen consumption level of 1.7 l/min under water is graded as “working hard” and a level of 2.5 l/min as “extreme exertion”. An average work load causes an oxygen consumption level of between 0.8-1.4 l/min. If these tested results are given a single value of 1.33 l/min, the normal consumption level of a diver, finning constantly under water, can be approximated.

Note:
Currently Spherasorb has no manufacturer test results for its use in diving units. The values presented here are a result of US Navy tests.

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Module E 8 Equipment Preparation

At the end of this module you should be able to describe the steps needed to prepare the unit for a dive.

Checking the Dosage

See “**Checking the Constant Flow**” (page 58)

The choice of appropriate nozzle, relating the choice of mix to the planned maximum depth (given a PO_2 = 1.4 bar/1.6 bar), can be found in the table below:

MOD (Maximum Operating Depth)				
Gas mix	normal Flow in l/min	Colour-Coding	max. depth 1.4 bar	max. depth 1.6 bar
60% O_2	5.8	Black	13 m	16 m
50% O_2	7.3	Red	18 m	22 m
40% O_2	10.4	Blue	25 m	30 m
32% O_2	15.6	none	33 m	40 m

Table 17

Filling the Absorber Canister

Fill the cartridge with absorber to a level of about one-half and lightly tap the cartridge wall with the flat of your hand to settle the contents. Never bang the cartridge on the floor or a hard surface. Fill the cartridge and repeat the tapping. After the absorber granulate has settled sufficiently, place the cartridge collar onto the surface of the absorber with the edge face-up. Then continue to fill the cartridge until the full-marker is reached. Lightly blow off any unwanted chemical dust and then close and seal the canister and perform a pressure test. To do this, seal the outlet pipe with the palm of a hand and blow forcefully into the inlet pipe. No air should escape from around the seal of the canister lid.

Note!

- **In contact with excessive moisture or water the absorber produces caustic foam. Should this come into contact with the skin rinse immediately with copious quantity of fresh water.**
- **Refill the absorber canister before diving. This should be done only shortly before the dive commences!**
- **Storing an already filled canister is not permitted.**
- **Before filling, ensure that the two sieves are not clogged.**
- **Do not allow residual absorber dust into the cartridge when filling. This can permeate through the protective sieve and enter the counterlung.**
- **Protect the filled canister from exposure to excessive heat. Dried-out chemicals have reduced capability to absorb CO_2!**
- **Always adhere to the manufacturers recommendations.**

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Convoluted Hoses
To check the correct function of the non-return valves, hold the not yet mounted hoses (green) – with closed mouthpiece barrel - to the mouth and blow air through the hose in the correct flow direction. Non-return valves open, the air flows through –OK! Then repeat this from the other end (red), blowing air against the correct flow direction. Non-return valves remain closed, no gas flows through – OK!

To check the correct assembly we use the following pressure tests:

Pressure test - exhale counterlung
Use a rubber stopper to seal the exhale connector to the absorber canister. Then perform the following tests. If the tests reveal a leak you should not dive with the unit until the cause is found and remedied!

Positive pressure test - exhale counterlung (only for old coaxial configuration)

The breathing hoses are first fitted to the unit. Differing fittings prevent incorrect assembly. Close overpressure valve. Inflate the counterlung fully via the mouthpiece until the gas starts to vent via the overpressure valve. Close the mouthpiece and check the counterlung for signs of pressure loss.

As shown left, place a 1 to 2kg lead weight on the centre of the counterlung. The weight should not noticeably sink over a period of 60 secs.

It is not necessary to conduct the positive pressure test of the exhale counterlung if the unit has the newer, separate counterlungs. A negative pressure test is however essential.

Negative pressure test
The counterlungs should be sucked dry. With the exterior protective cover of the counterlungs open, the inner bag (coaxial version) is checked for signs of relaxation for at least one minute. For the separate bag version both lungs are checked for signs of relaxation for one minute.

Following the test, do not forget to return the overpressure valve to your personal setting.

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Check cylinder contents
Open the cylinder valves and check the manometers. With a suitable analyser both mixtures should be analysed. The measuring adapter of the Oxyscan A can be used. Reclose the valves if the unit is not in use in order to avoid constant gas loss due to the constant-flow operating mechanism.

Check Octopus
By breathing from the octopus you can check whether it delivers gas on demand and, by briefly depressing the purge, whether it is likely to free-flow.
Note: The octopus is not a complete bail-out safeguard. It is rather just an additional safety factor!

Reserve bail-out gas
The use of a bail-out system is essential. Various options are possible. We recommend the use of a side-mounted 4-litre cylinder with first and second stages. This can also be used for inflating the drysuit or buoyancy compensator. (See **Module E3** page 60)

Check Bypass valve
Open cylinder valve, inhale gas through the open mouthpiece and release it through the nose until the counterlung is fully empty. Inhale further – gas must flow immediately through the bypass-valve in sufficient quantity to balance the demand.
The adjustment of the bypass valve should only be carried out by a service technician!

Check Buoyancy Compensator

Prior to each use the BC should be carefully checked to ensure it is functioning properly. All vents should be operating without hindrance. To perform a pressure test inflate the jacket and let it stand for some time. If a leak is found, this must be repaired before any further dives are carried out. Also check the function of the Inflator and over pressure valve. Finally vent the BC fully.

Loop flush
Cylinder valves should only be opened just before commencing the dive. Following this the loop should be flushed three times by inhaling through the mouthpiece and exhaling through the nose.

Note: After flushing the loop do not remove the mouthpiece again. Refrain from inhaling normal air just prior to descent!

Attention!
Never attempt to dive with the Submatix, if the checks listed above reveal leaks. In such a case the unit should be disassembled again and all hose connections checked.

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`Pre-Dive´ check list

The following list should be checked through prior to EVERY dive:

	✓
1. Cylinder pressure checked and contents analysed?	
2. Constant flow correctly set for the mix?	
3. Absorber canister cleaned, correctly filled and sealed? Shake test rattle-free?	
4. Non-return valves tested on both sides?	
5. Negative pressure test on loop - any leaks?	
6. Positive pressure test on loop – any leaks?	
7. Constant flow OK?	
8. Unit correctly mounted. All clips closed correctly?	
9. Mouthpiece correctly aligned, barrel closed?	
10. Pressure gauge OK?	
11. Oxyscan OK?	
12. Bail-out OK?	
13. Loop flushed?	

Self-assessment quiz

E8 1. Which information on the cylinder tag should be re-checked prior to diving?
E8 2. The constant flow gas nozzle must correspond to what?
E8 3. What should be paid attention to when filling the absorber canister?
E8 4. How are the convoluted hoses tested prior to assembly?
E8 5. Describe the negative pressure test:
E8 6. Describe the positive pressure test:
E8 7. Describe how a loop flush is performed:

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Module E 9 Dive Techniques for the Submatix

At the end of this module you should be able to describe the best dive techniques for the Submatix 100 ST.

Note!
On descent – between 2-3 metres let your diving partner check whether there are any visible leaks from your unit (ascending bubbles) and listen yourself for any gurgling noises. Pay attention to the normal function sounds (non-return valves, constant flow, and over-pressure valve). Observe the special hand signals.

Practical tips
The tips given in this module are the result of experience gained over many dives with the SCR 100 ST rebreather conducted in diverse conditions. Nonetheless, neither Submatix nor the training organization will accept responsibility for any accidents arising through their use!

The ideal breathing comfort is obtained by using the SUBMATIX weight harness in combination with the SUBMATIX BC-collar. Jackets, or wings, lift the unit away from the diver and this increases the WOB.

Weighting
SUBMATIX recommends placing 2x2 or 2x3 kg weights in the upper left-hand and right-and side of the base plate section of the housing, and a further 2 kg to be placed centrally under the counterlungs: This neutralizes the positive buoyancy of the unit and offers the diver an optimum swimming position.

Descent
Directly before entering the water both cylinder valves should be opened and before beginning the descent the loop must be flushed to safely avoid a hypoxic situation caused by falling ppO_2 levels at shallow depths from occurring. This is accomplished by inhaling from the loop and exhaling through the nose three times. Following this flush the mouthpiece should not be removed again to avoid re-inhaling ambient gas! To begin the descent, vent gas from the buoyancy compensator. The familiar method of exhaling used for open circuit does not work well as here the gas drawn from the counterlung is immediately replaced due to the constant flow. Avoid fast descents as, in addition to the constant flow, the bypass valve will open in order to maintain loop volume if ambient pressure increases too rapidly. This is an inefficient use of gas.

During the dive, depth should be held as constant as possible. “Saw-tooth” profiles waste a lot of gas. Each time a reduction of depth occurs the gas in the counterlung will expand and some will be vented and lost through the overpressure valve. Additionally, buoyancy control will be affected and continual compensation will be necessary. During the dive, you should also concentrate on the typical sounds, for example, the regular opening of the bypass valve as well as the constant flow of gas into the loop. If the typical sounds are not to be heard you should react accordingly.

Furthermore, you should regularly check the OXYSCAN 100 PRO readings.

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Note: During longer dives moisture condenses in the breathing hoses and this causes some gurgling noises. These noises differ from the gurgling caused by a sudden leak in that they do not appear suddenly, but rather increase slowly. Such condensation is normal and does not adversely affect the performance of the unit.

Breathing techniques of the SCR 100 ST

Due to the nature of its construction, such as the patented co-axial counterlungs, the breathing resistance of the SCR 100 ST is relatively low. Nevertheless it is noticeably different to the breathing comfort of open circuit regulators. This means that the diver will need a few dives to get accustomed to the new “Feeling“. The first step is to determine your own individual setting for the over pressure valve.

In comparison to open circuit the diver first becomes aware of a “full mouth”. This is quickly alleviated by exhaling the excess gas through the nose or around the sides of the mouthpiece. Nonetheless, pressure will once again begin to increase as gas flows constantly into the loop. This can cause a lot of gas to be wasted.

It is therefore important to set the overpressure valve correctly. It should be set to trigger with the minimum of pressure by rotating fully to the left (anti-clockwise). In this position the best compromise between WOB, inhalation volume available and positive buoyancy is established. The necessary adjustment is best carried out with the aid of a buddy in a pool or on a shallow platform. The overpressure valve should only be set to trigger at higher pressures for dives beyond 20m in depth.

Due to its construction characteristics, the WOB will vary depending on the body attitude of the diver in the water. Initial acclimatization to this is best conducted in a pool.

Due to the exothermic reaction of the absorber chemical as well as the repeated recirculation of the breathing gas it will remain warm and moist. This prevents a drying-out of the airways and noticeably reduces the loss of body warmth.

During the dive breathe slowly and relaxed! There is no point in breath-holding or skip-breathing as the constant flow will be unaffected and no improvement in gas efficiency is to be gained from such techniques.

Pay attention to correct buoyancy and trim. Make yourself as streamlined as possible. Avoid sudden changes of depth as these could cause loss of buoyancy control!

Ascent

Before beginning the ascent the loop must be flushed in the usual way to safely avoid a hypoxic situation caused by falling pO_2 levels at shallow depths from occurring.

During ascent excess expanding gas will be vented via the overpressure valve. Slow ascents help reduce the amount of bubble formation. Correct, neutral buoyancy control is essential in this situation.

If the overpressure valve, due to its setting and due to an overly fast ascent, is unable to vent gas quickly enough, it is possible to release unwanted volume and pressure by exhaling through the nose.

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Always observe a safety stop of 3min/5m.

After the safety stop ascend directly to the surface.

When the dive is over, remove the mouthpiece from your mouth only after the barrel has been closed. Immediately afterwards close the cylinder valve to prevent gas wastage. Once the cylinder valve has been closed do not breathe from the loop again –there is a danger of hypoxia! Lie on your back if a swim to the boat or shore is necessary.

Beware!
Never attempt to swim long distances on the surface breathing from the loop as this can induce the risk of hypoxia.

Self-assessment quiz

E9 1. What checks should be performed immediately after initial descent?
E9 2. Why should fast descents be avoided?
E9 3. What problems arise from saw-tooth dive profiles?
E9 4. Why is it necessary that the mask fits extremely well?
E9 5. What should be done directly before the start of the dive?
E9 6. During ascent, how can excess gas be vented?
E9 7. Is it sensible to swim on the surface breathing from the loop?

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Module E 10 Post-Dive Care

Checklist after surfacing

1. **Close mouthpiece**
2. **Remove mouthpiece from mouth**
3. **Close cylinder valves**
4. **Check contents gauges**

A) Prior to a **further dive**

After **finishing a dive** there are several things to be done:

- Close the mouthpiece
- Close the Nitrox cylinder valves to avoid unnecessary loss of pressure due to the constant flow. The residual pressure in the system will automatically bleed-off.
- Rinse the unit off in fresh water after first ensuring that the mouthpiece is closed.
- Remove housing lid and visually check the colour indicator of the absorber. Replace if exhausted.
- Check for signs of leaks. Water in the counterlungs? In the absorber canister?
- Thoroughly rinse breathing hoses and counterlungs with fresh water, disinfect with approved product (Easy Clean Spray), and rinse again. Allow parts to air out.
- Empty absorber canister if spent. Rinse it in fresh water, remove residual dust with soft brush or cloth and allow to dry
- Allow all parts to dry in a shaded place. Direct sunlight should be avoided.
- Check for signs of damage
- Check cylinder contents and refill as appropriate
- Check bail-out system
- Refill bail-out cylinder(s)
- Pressure test

Note!
The loop is a breeding ground for bacteria. Therefore scrupulous cleanliness and hygiene during post-dive maintenance is essential to maintain the equipment in good order and protect your own health!

As the counterlung generally does not dry out well, it is best to rinse and disinfect it each time the absorber canister must be refilled. In the same way, it is recommendable to also periodically disinfect the breathing hoses and mouthpiece.

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It goes without saying that if the unit is swapped from one diver to another all loop parts should be cleaned and disinfected.

After the dive the complete unit should be rinsed down with fresh water. The breathing loop components should be allowed to dry fully and then carefully stored. In particular all connections, the mouthpiece and the cylinder valves should be checked for cleanliness and ease of movement. If necessary they should be lightly greased.

B) For storage

- Thoroughly rinse unit with fresh water
- Remove breathing hoses, Rinse and disinfect hoses and counterlungs (EW 80), Rinse again with fresh water and allow to dry
- Empty absorber canister and clean out residual dust. Rinse if necessary.
- Check all O-ring seals are clean and O-rings in good condition. If necessary, lightly smear with approved grease.
- Store the unit and all loop components in a dark, cool and dry environment

Note!

- **Only lubricate with approved grease!**
- **Never use silicone grease or oil on parts exposed to high pressure!**

Tip: Between two dives performed on the same day, it is not essential to renew the absorber if the elapsed time allows enough residual usage to perform the second dive.

Equally, disinfection between two such dives can be omitted if the same diver will be using the unit for the second dive.

Important: As the breathing loop provides ideal conditions for almost all types of bacteria to flourish, some will undoubtedly take hold unless regular disinfection is carried out. By using transparent material for the counterlungs it is easy to visually check for signs of contamination.

After each diving day the unit should be rinsed thoroughly, disinfected and allowed to dry.
Storage should be in an appropriate cool, dark, well-circulated environment
All Pro - Con snap connectors should be checked and, if necessary, lightly lubricated (Molykote).

Self-assessment quiz

E10 1. Why is it important to disinfect the unit at the end of each diving day?
E10 2. Why should the cylinder valves be closed directly after the end of the dive?
E10 3. Must the loop be disinfected after every dive?
E10 4 Which disinfectants are appropriate?

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Module E 11 Emergency Procedures, Exercises and Problem Solving

At the end of this module you should be able to determine whether a problem can be solved during the dive and, if not, what emergency measures should be taken.

Attention!

Safety routine:

If a problem occurs during a dive, the following rule applies:
Close the mouthpiece and switch to OC bail out.

If in doubt, bail out!

Loss of the mouthpiece
Should you lose the mouthpiece underwater, it will float upwards. In this case lean back, look up and locate it, then replace it. As in this circumstance the mouthpiece was not closed, some water may have entered the loop. Breathe in carefully at first and listen for gurgling noises. If gurgling can be detected, it is safest to switch to open circuit and terminate the dive. However, due to the integral water traps some water can enter the loop without disrupting the function of the unit.

Vomiting under water
Vomiting into the mouthpiece could block the breathing hoses. If you find it necessary to vomit under water, switch to open circuit first and retain regulator in mouth to avoid swallowing water. Don’t forget to close the mouthpiece prior to switching to OC!

Flooded Loop
Close mouthpiece and switch to open circuit bail-out.

Exhausted Absorber
A raised breathing frequency without any obvious exertion may indicate that the absorber is exhausted. (See **module D13** Hypercapnia, page 28)
Close mouthpiece and switch to bail-out system.

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Part III Practical Training

Module F 1 Equipment Preparation, Pre-Dive-Checks

- Check dive plan: maximum depth and dive time
- Check gas mix, cylinder content
- Fit the correct flow-nozzle for the chosen mix
- Fill the absorber canister
- Check functions of unit: Pressure test, mouthpiece barrel, constant flow
- Check bail-out system

Pre Dive Check List

The following checks should be carried out before every dive:	
Analyse gas in the Nitrox cylinder	
Check that the correct nozzle has been installed for chosen mix	
Check dive plan, MOD and dive time	
Check the absorber –replace if necessary	
Check the fill pressure of both cylinders and connect to unit	
Connect all hoses and check seals carefully	
Check non-return valves in the mouthpiece are functioning correctly	
Positive and negative loop pressure test	
Open and control cylinder valves (turning smoothly and easily?)	
Check all inflators are functioning correctly	
Check the bail-out regulator	
Check constant-flow operation	
Check Oxygauge (if fitted)	
3 minute pre-breathe test	

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Module F 2 Practical Training Exercises

Attention!

Maximum depth for CW training	**5 metres**
Maximum depth for OW dive 1	**10 metres**
Minimum and maximum depth for OW dives 2 - 4	**20 and 30 metres**
Minimum total in-water time	**240 minutes**

Exercises: Confined Water (max. 5m)

Routine exercises (Remove and replace unit on the surface, open and close rotating mouthpiece, buoyancy control, flushing, and experiment with various swimming positions)

30-60 minutes dive and exercise time

Before the dive:

- Plan dive
- Pre-dive check
- Open and close rotating mouthpiece to check for smoothness of operation
- Buddy-check
- Close mouthpiece

Prior to descent:

- Open cylinder valve
- Check and if necessary adjust the overpressure valve

During dive:

- Check buoyancy
- Slow descent, perform bubble check with partner
- Short swim with buoyancy control exercises
- Adopt differing body positions. Note effect on WOB
- Several switches to bail-out supply and back
- Trigger the bypass-valve
- Slow controlled ascent
- Close mouthpiece
- Close cylinder valve
- Rescue exercises (initial response, CBL and in-water EAR)

Note!
If OW training is to be conducted with the 100 XT version of the Submatix using two differing Nitrox mixes, your instructor will give you time to become accustomed to the gas switching block and will expect you to plan and perform a gas switch during OW dives 2 + 3.

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Exercises: Open Water Dive 1 (max. 10m)

Before the dive:

- Plan dive
- Pre-dive check
- Open and close rotating mouthpiece to check for smoothness of operation
- Buddy check
- Close mouthpiece

During dive*:*
Check and if necessary adjust the overpressure valve
Descend to approx. 6m: check buoyancy control and perform bubble check
Rolls, turns etc, to experience fluctuations in WOB in relation to body attitude
Switch to bail-out and back to loop
Flush the loop and perform a slow, controlled ascent
After ascent close mouthpiece and cylinder valve

Exercises: Open Water Dive 2 (min. 20m - max. 30m)

Before the dive:

- Plan dive
- Pre-dive check
- Open and close rotating mouthpiece to check for smoothness of operation
- Buddy-check
- Close mouthpiece

During dive:
Descent, buoyancy control, bubble check U/W
Adjust over pressure relief valve
Rolls, turns etc, to experience fluctuations in WOB in relation to body attitude
Several switches from loop to bail-out and back
“Loss” and recovery of mouthpiece (close mouthpiece prior to “loss”!)
Flush loop
Locate own bail-out regulator, close mouthpiece, take several breathes from bail-out system, return to loop.
Initial response to unconscious buddy
Safety stop on ascent

Exercises: Open Water Dive 3 (min. 20m - max. 30m)

Descent, bubble check U/W, adjust over pressure relief valve
Initial response to unconscious buddy
Bail-out swimming, bail-out ascent with safety stop

Exercises: Open Water Dive 4 (min. 20m - max. 30m)

Descent, bubble check U/W, adjust over pressure relief valve
Bail-out swimming
Initial response to unconscious buddy, CBL and in-water EAR
Remove unit without help on the surface

Total dive time for open water should not be less than 180 minutes

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Module F 3 Special Hand Signals

The hand signals for:

Is my unit leak-free?

Index finder of the right hand held vertically and bent forward to form a question mark. (?) Rest of hand forms a closed fist.

The unit is leak-free

The thumb and fingers of the right hand form an open barrel shape. This is then “closed” by placing the flat of the left hand over the top of the barrel.

Bubbles “pearling” out from partner’s equipment

Index and forefinger move in a quick “walking” motion and the hand moves simultaneously upwards.

Water in loop

Index finger of the right hand moves in a wave motion and then points to source of leak.

Flush the loop!

With the index and forefinger held straight and tight together, touch the tip of the nose and then move fingers away in an upward sweep.

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APPENDIX I

Glossary

Absorber: A chemical filter that removes CO_2 from exhaled gas.

Bail-Out: An emergency procedure that terminates the dive; the bail-out system is the technical configuration that enables the diver to leave the loop. This is usually, but not always, an open circuit regulator.

Breakthrough: The point at which the absorber can no longer completely bind the exhaled CO_2. This leads to a rapid increase in loop pCO_2.

Bypass/ADV: A valve that either automatically or manually supplements the constant flow supply when necessary, to provide further gas to the loop

Canister: The container holding the chemical CO_2 absorber. (Spherasorb)

Caustic Cocktail: Acidic foam created when water comes into contact with CO_2 absorber. If inhaled, this can cause burning of the mouth and airways. Due to the water traps in the rebreather the likelihood of such a caustic cocktail reaching the diver is almost zero.

Closed circuit: A rebreather where gas is only vented on ascent. These include oxygen rebreathers and constant pO_2 rebreathers such as the Inspiration. CO_2 must be fully absorbed and, in the case of constant pO_2 rebreathers, electronic sensors are needed to regulate the gas mix in the loop.

CNS-loading: The level of CNS oxygen exposure related to dive time and the gas mix used.

CNS-toxicity: Toxic effect of oxygen on the central nervous system occurring if oxygen partial pressure is excessively high.

CO_2: Carbon dioxide. An odourless gas produced as a by-product of oxygen metabolism. Even small quantities are poisonous. CO_2 build-up is the breathing "trigger" - not lack of oxygen.

Constant flow: A constant injection of gas into the loop commonly used in SCR's. The flow rate (l/min) is dependant upon the oxygen % in the gas supply and is regulated by the constant flow valve. On some units this valve is adjustable / exchangeable whereas on others the valve is fixed.

Co-axial Counterlungs: The exhale counterlung is situated within the inhale counterlung to reduce WOB. This concept was developed and patented by Submatix.

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DSV Diluent supply valve – an open circuit bailout regulator incorporated in the loop mouthpiece

HLF: Half-life recovery factor - used to calculate the percentual reduction of the CNS loading in relation to surface interval time.

Hypercapnia: An increase in the CO_2-concentration (pCO_2) in the blood above the normal level of 45 mm/Hg caused by breathing CO_2-rich gas.

Hyperoxia: Excessive O_2 at cell level

Hypoxia: Condition where O_2-starvation occurs in body tissues.

Loop: All mechanical components of the breathing circulation including counterlung(s), convoluted hoses, canister and mouthpiece. Additionally the diver’s own respiratory system and the air space within the mask

MPSS Maximum Pressure Select System; A gas switching block designed and patented by Submatix

NOAA: National Oceanic and Atmospheric Administration

OC-system A conventional regulator used as emergency back-up. Gas is breathed only once and then lost to the surrounding water.

pO_2 / ppO_2: Partial pressure of oxygen.

Pro-Con Hose connection system designed and patented by Submatix.

SCR: **S**emi **C**losed **R**ebreather (see Semi-closed)

Semi-closed: A quantity of the loop gas is periodically vented via an overpressure valve and replenished by a constant flow of fresh gas into the loop. This guarantees an adequate pO_2 and reduces the chance of a carbon dioxide build-up. Gas consumption is therefore depth dependant.

Scrubber: The CO_2 absorber material

Stack: Commonly used slang for the canister and CO_2 absorber.

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APPENDIX II

Tables

Loop oxygen levels related to the actual O_2-consumption			
O_2% of the premix		O_2-consumption (Workload)	O_2% in the loop
32%	15 l/min	0,75	38,0
		1,25	26,0
		1,5	24,0
		2,25	20,0
40%	10 l/min	0,75	35,0
		1,25	31,0
		1,5	29,0
		2,25	23,0
50%	6 l/min	0,75	43,0
		1,25	37,0
		1,5	35,0
		2,25	20,0
60%	5 l/min	0,75	53,0
		1,25	47,0
		1,5	43,0
		2,25	27,0

Table 3

EXPOSURE TIME LIMITS				
bar	Per Dive		24 Hr. Maximum	
	(Minutes)	(Minutes)	(Minutes)	(Stunden)
1.6	45	0.75	150	2.5
1.5	120	2.0	180	3.0
1.4	150	2.5	180	3.0
1.3	180	3.0	210	3.5
1.2	210	3.5	240	4.0
1.1	240	4.0	270	4.5
1.0	300	5.0	300	5.0
0.9	360	6.0	360	6.0
0.8	450	7.5	450	7.5
0.7	570	9.5	570	9.5
0.6	720	12.0	720	12.0

Table 4

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NOAA Oxygen Partial Pressure and Exposure Time Limits for Nitrogen - Oxygen Mixed Gas Dives				
pO_2	O_2 Single Exposure		24 Hour Total Exposure	
bar	min.	hr	min.	hr
1.6	45	.75	150	2.5
1.5	120	2.0	180	3.0
1.4	150	2.5	180	3.0
1.3	180	3.0	210	3.5
1.2	210	3.5	240	4.0
1.1	240	4.0	270	4.5
1.0	300	5.0	300	5.0
0.9	360	6.0	360	6.0
0.8	450	7.5	450	7.5
0.7	570	9.5	570	9.5
0.6	720	12.0	720	12.0

Table 5 (The values have been rounded-up for simplicity)

ppO_2	CNS-exposure limit Maximum (in min)	CNS % (Per min.)	OTU (Per min.)
0.60	720	0.14	0.26
0.70	570	0.18	0.47
0.75	500	0.20	0.56
0.80	450	0.22	0.65
0.85	400	0.25	0.74
0.90	360	0.28	0.83
0.95	333	0.30	0.92
1.00	300	0.33	1.00
1.05	270	0.37	1.08
1.10	240	0.42	1.16

ppO_2	CNS-exposure limit Maximum (in min)	CNS % (Per min.)	OTU (Per min.)
1.15	227	**0.44**	1.24
1.20	210	0.47	1.32
1.25	196	0.51	1.40
1.30	180	0.56	1.48
1.35	164	0.61	1.55
1.40	150	0.65	1.63
1.45	139	0.72	1.70
1.50	120	0.83	1.78
1.55	90	1.11	1.85
1.60	45	2.22	1.92

Table 6

CNS – Half-life Factors						
Interval Time: in hrs.	0:30	1:00	1:30	2:00	2:30	3:00
HL-Factor: x CNS %	0.80	0.63	0.50	0.40	0.31	0.25
Interval Time: in hrs.	3:30	4:00	4:30	5:00	6:00	9:00
HL-Factor: x CNS %	0.20	0.16	0.13	0.10	0.06	0.01

Table 7

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EAD Table								
Depth (in m)	32% O_2		40% O_2		50% O_2		60 % O_2	
	EAD	ppO_2	EAD	ppO_2	EAD	ppO_2	EAD	ppO_2
6	4.0	0.50	2.2	0.64	0.1	0.80	- 1.9	0.96
10	7.5	0.62	5.2	0.70	2.7	1.00	0.1	1.20
12	9.2	0.68	6.7	0.88	3.8	1.10	1.1	1.32
14	11.0	0.74	8.2	0.96	5.2	1.20	**2.2**	**1.44**
16	12.7	0.81	9.7	1.04	6.5	1.30	**3.2**	**1.56**
18	14.5	0.87	11.3	1.12	7.7	1.40	**4.2**	**1.68**
20	16.2	0.93	12.8	1.20	**9.0**	**1.50**	**5.2**	**1.80**
22	17.4	0.99	14.3	1.28	**10.3**	**1.60**	**6.2**	**1.92**
24	19.7	1.05	15.8	1.36	**11.5**	**1.70**	**7.2**	**2.04**
26	21.4	1.12	**17.3**	**1.44**	**12.8**	**1.80**	**8.2**	**2.16**
28	23.2	1.18	**18.9**	**1.52**	**14.1**	**1.90**	**9.2**	**2.28**
30	24.9	1.24	**20.4**	**1.60**	**15.3**	**2.00**	**10.3**	**2.40**
35	29.3	1.40	**24.2**	**1.80**	**18.5**	**2.25**	**12.8**	**2.70**
40	**33.7**	**1.55**	**28.0**	**2.00**	**21.6**	**2.50**	**15.3**	**3.00**
42	**35.4**	**1.61**	**29.5**	**2.08**	**22.9**	**2.60**	**16.3**	**3.12**

Table 8

Days	OTU's / Days	Total	Days	OTU's / Days	Total
1	800	800	9	330	2970
2	700	1400	10	310	3100
3	650	1950	11	300	3300
4	525	2100	12	300	3600
5	460	2300	13	300	3900
6	420	2520	14	300	4200
7	380	2660	15	300	/
8	350	2800	20	300	/

Table 9

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Dosage nozzles and maximum operating depths			
O_2 %	Colour coding	ppO_2 1.4 bar	ppO_2 1.6 bar
80 %	Green	8 m	10 m
60 %	Black	13 m	16 m
50 %	Red	18 m	22 m
40 %	Blue	25 m	30 m
32 %	Yellow	33 m	40 m

Table 10

Tolerances for the constant flow setting		
Gas mix	Minimum flow (L/min)	Maximum flow (L/min)
80 % green	3.0	4.3
60 % black	5.0	6.4
50 % red	6.0	7.95
40 % blue	9.4	11.3
32 % yellow	14.2	16.9

Table 11

Nitrox mix	Dosage l/min	Flow rate	loop mix	Max. duration of the constant dosage 4lt / 200 bar Res 30 bar	Max. duration of the constant dosage 4 lt / 300 bar Res 30 bar
	0.75	3.0	73 % O_2	226 min	339 min
80 % O_2	1.25	3.0	66 % O_2	226 min	339 min
	2.25	3.0	20 % O_2	226 min	339 min
	0.75	5.0	53 % O_2	135 min	204 min
60 % O_2	1.25	5.0	47 % O_2	135 min	204 min
	2.25	5.0	27 % O_2	135 min	204 min
	0.75	6.0	43 % O_2	113 min	156 min
50 % O_2	1.25	6.0	37 % O_2	113 min	156 min
	2.25	6.0	20 % O_2	113 min	156 min
	0.75	10	35 % O_2	68 min	102 min
40 % O_2	1.25	10	31 % O_2	68 min	102 min
	2.25	10	23 % O_2	68 min	102 min
	0.75	15	38 % O_2	45 min	67 min
32 % O_2	1.25	15	26 % O_2	45 min	67 min
	2.25	15	20 % O_2	45 min	67 min

Table 12

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Nitrox mix	O_2 consumption l/min	Dosage l/min	FiO_2	FiN_2
80 % O_2	0.75	3.0	73 % O_2	27 % N_2
	1.25	3.0	66 % O_2	34 % N_2
	2.25	3.0	20 % O_2	80 % N_2
60 % O_2	0.75	5.0	53 % O_2	47 % N_2
	1.25	5.0	47 % O_2	53 % N_2
	2.25	5.0	27 % O_2	73 % N_2
50 % O_2	0.75	6.0	43 % O_2	57 % N_2
	1.25	6.0	37 % O_2	63 % N_2
	2.25	6.0	20 % O_2	80 % N_2
40 % O_2	0.75	10	35 % O_2	65 % N_2
	1.25	10	31 % O_2	69 % N_2
	2.25	10	23 % O_2	77 % N_2
32 % O_2	0.75	15	38 % O_2	62 % N_2
	1.25	15	26 % O_2	74 % N_2
	2.25	15	20 % O_2	80 % N_2

Table 13

EAD Table

Depth (in m)	32 % O_2		40 % O_2		50 % O_2		60 % O_2		80 % O_2	
	EAD	ppO_2	EAD	ppO_2	EAD	ppO_2	EAD	ppO_2	EAD	ppO_2
6	4.0	0.50	2.2	0.64	0.1	0.80	-1.9	0.96	-5.9	1.28
10	7.5	0.62	5.2	0.70	2.7	1.00	0.1	1.20	-4.9	1.60
12	9.2	0.68	6.7	0.88	3.8	1.10	1.1	1.32	-4.4	1.76
14	11.0	0.74	8.2	0.96	5.2	1.20	2.2	1.44	-3.9	1.92
16	12.7	0.81	9.7	1.04	6.5	1.30	3.2	1.56	-3.4	2.80
18	14.5	0.87	11.3	1.12	7.7	1.40	4.2	1.68	-2.9	2.24
20	16.2	0.93	12.8	1.20	9.0	1.50	5.2	1.80	-2.4	2.40
22	17.4	0.99	14.3	1.28	10.3	1.60	6.2	1.92	-1.8	2.56
24	19.7	1.05	15.8	1.36	11.5	1.70	7.2	2.04	-1.3	2.72
26	21.4	1.12	17.3	1.44	12.8	1.80	8.2	2.16	-0.8	2.88
28	23.2	1.18	18.9	1.52	14.1	1.90	9.2	2.28	-0.3	3.04
30	24.9	1.24	20.4	1,60	15.3	2.00	10.3	2.40	0.12	3.20
35	29.3	1.40	24.2	1.80	18.5	2.25	12.8	2.70	1.3	3.60
40	33.7	1.55	28.0	2.00	21.6	2.50	15.3	3.00	2.6	4.00
42	35.4	1.61	29.5	2.08	22.9	2.60	16.3	3.12	3.2	4.16

Table 14

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Oxygen consumption			FiO_2 in relation to O_2-consumption							
			Premix 60%		Premix 50%		Premix 40%		Premix 32%	
workload		l/Min	Factor	FiO_2	Factor	FiO_2	Factor	FiO_2	Factor	FiO_2
high	**h**	**2.5**	0.50	**30%**	0.50	**25%**	0.55	**21%**	0.594	**19%**
	g	**2.0**	0.65	**39%**	0.64	**32%**	0.65	**26%**	0.688	**22%**
	f	**1.75**	0.716	**43%**	0.70	**35%**	0.70	**28%**	0.719	**23%**
normal	**e**	**1.5**	0.766	**46%**	0.76	**37%**	0.75	**30%**	0.781	**25%**
	d	**1.25**	0.816	**49%**	0.80	**40%**	0.80	**32%**	0.812	**26%**
	c	**1.0**	0.866	**51%**	0.86	**42%**	0.85	**33%**	0.844	**27%**
low	**b**	**0.75**	0.90	**54%**	0.90	**44%**	0.875	**35%**	0.906	**28%**
	a	**0.5**	0.933	**56%**	0.92	**46%**	0.925	**37%**	0.937	**30%**

Table 15 (the FiO_2values have been rounded-up)

Carbon Dioxide Absorption of SPHERASORB/SOFNOLIME			
CO_2 absorption	CO_2 production	Using time of scrubber at 1.7 kg filling	Water temperature
Sofnolime CD 100 l/min	1.2 l/min	140 min	4°C
	1.6 l/min	105 min	4°C
Spherasorb 120 l/min	1.2 l/min	170 min	4°C
	1.6 l/min	125 min	4°C
Sofnolime 797	1.2 l/min	198 min	4°C
	1.6 l/min	148 min	4°C

Table 16

MOD (Maximum Operating Depth)				
Gas mix	normal Flow in l/min	Colour-Coding	max. depth 1.4 bar	max. depth 1.6 bar
60% O_2	5.8	Black	13 m	16 m
50% O_2	7.3	Red	18 m	22 m
40% O_2	10.4	Blue	25 m	30 m
32% O_2	15.6	none	33 m	40 m

Table 17

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APPENDIX III

Formulae:

⇒ Absolute pressure (P) = $\left(\frac{\text{Depth}}{10}+1\right)$

⇒ Dalton’s law = $\frac{\text{Pg}}{\text{P} \mid \text{Fg}}$

⇒ Best mix = $\text{Fg}=\frac{\text{Pg}}{\text{P}}$

⇒ CNS-limit = $\text{PO}_2=\text{FO}_2 \text{ x } \left(\frac{\text{Depth}}{10}+1\right)$

⇒ MOD (max. operating depth) = $\left(\frac{\text{PO}_2}{\text{FO}_2}-1\right) \text{x } 10$

⇒ EAD (equivalent air depth) = $\left(\frac{\text{FN}_2 \text{ x } (\text{Depth}+10)}{0.79}\right)-10$

⇒ SCR formula = $\text{FiO}_2=\frac{(\text{Vs x FsO}_2)-\text{VO}_2}{\text{Vs}-\text{VO}_2}$

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APPENDIX IV

Quality control checklist - training exercises

Quality control: Pool/confined water

No:	Exercise	Signature/ Initials participant	Signature/ Initials Instructor	Date Of exercise
1	Pre-dive check			
2	3 minute pre-breathe			
3	Weight/buoyancy and trim check			
4	Bubble check partner			
5	Short swim with buoyancy control exercises			
6	Adopt differing body positions. Note effect on WOB			
7	Close and remove mouthpiece, replace, clear and open			
8	Overhead recovery of mouthpiece			
9	Bail-out, open circuit (in-board gas)			
10	Clear flooded mask and (optional) swim without mask			
11	Trigger the bypass-valve			
12	Rescue technique: Simulation „unconscious diver": Flush the diver's loop with diluent whilst simultaneously venting excess gas via the overpressure valve and securing mouthpiece			
13	Controlled ascent by venting expanding gas via the overpressure valve and/or through mouth/nose			
14	Controlled buoyant lift of "unconscious" buddy. Ensure casualty is positively buoyant at the surface			
15	Perform simulated in-water expired air resuscitation (EAR). One breath every five seconds. (Instructor should allow student to try various EAR and towing techniques)			
16	Close mouthpiece and cylinder valve			
Add stage cylinder and allow student enough time UW to get the feel of buoyancy control changes before performing next exercise:				
17	OC bail-out to off-board stage (swimming horizontally). Return to loop after I minute			
18	Remove the unit on the surface without aid from partner			

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Quality control: open water dive 1

No:	Exercise	Signature/ Initials participant	Signature/ Initials Instructor	Date Of exercise
1	Pre-dive check			
2	3 minute pre-breathe			
3	Weight/buoyancy and trim check			
4	Bubble check partner			
5	Short swim with buoyancy control exercises			
6	Adopt differing body positions. Note effect on WOB			
7	Close and remove mouthpiece, replace, clear and open			
8	Overhead recovery of mouthpiece			
9	Bail-out, open circuit (in-board gas)			
10	Clear flooded mask and (optional) swim without mask			
11	Trigger the bypass-valve			
17	OC bail-out to off-board stage (swimming horizontally). Return to loop after I minute			
13	Controlled ascent by venting expanding gas via the overpressure valve and/or through mouth/nose			
16	Close mouthpiece and cylinder valve			

Quality control: open water dive 2

No:	Exercise	Signature/ Initials participant	Signature/ Initials Instructor	Date Of exercise
1	Pre-dive check			
2	3 minute pre-breathe			
3	Weight/buoyancy and trim check			
4	Bubble check partner			
5	Short swim with buoyancy control exercises			
6	Adopt differing body positions. Note effect on WOB			
7	Close and remove mouthpiece, replace, clear and open			
8	Overhead recovery of mouthpiece			
9	Bail-out, open circuit (in-board gas)			
11	Trigger the bypass-valve			
12	Rescue technique: Simulation „unconscious diver": Flush the diver's loop with diluent whilst simultaneously venting excess gas via the overpressure valve and securing mouthpiece			
13	Controlled ascent by venting expanding gas via the overpressure valve and/or through mouth/nose			
19	Safety stop for 3 min. at 5 metres			
16	Close mouthpiece and cylinder valve			
18	Remove the unit on the surface without aid from partner			

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Quality control: open water dive 3

No:	Exercise	Signature/ Initials participant	Signature/ Initials Instructor	Date Of exercise
1	Pre-dive check			
2	3 minute pre-breathe			
4	Bubble check partner			
7	Close and remove mouthpiece, replace, clear and open			
8	Overhead recovery of mouthpiece (swimming horizontally)			
11	Trigger the bypass-valve			
12	Rescue technique: Simulation „unconscious diver": Flush the diver's loop with diluent whilst simultaneously venting excess gas via the overpressure valve and securing mouthpiece			
17	OC bail-out to off-board stage (swimming horizontally). Return to loop after I minute			
20	OC Bail-out ascent			
19	Safety stop for 3 min. at 5 metres			

Quality control: open water dive 4

No:	Exercise	Signature/ Initials participant	Signature/ Initials Instructor	Date Of exercise
1	Pre-dive check			
2	3 minute pre-breathe			
4	Bubble check partner			
7	Close and remove mouthpiece, replace, clear and open			
8	Overhead recovery of mouthpiece (swimming horizontally)			
17	OC bail-out to off-board stage (swimming horizontally). Return to loop after I minute			
12	Rescue technique: Simulation „unconscious diver": Flush the diver's loop with diluent whilst simultaneously venting excess gas via the overpressure valve and securing mouthpiece			
14	Controlled buoyant lift of "unconscious" buddy. Ensure casualty is positively buoyant at the surface			
15	Perform simulated in-water expired air resuscitation (EAR). One breath every five seconds. (Instructor should allow student to try various EAR and towing techniques)			
18	Remove the unit on the surface without aid from partner			

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Exercise chart

No:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Pool																				
1																				
2																				
3																				
4																				

☐ yes ☐ no

Record of pool dive time:

Location	Date	Depth	Dive time		

Record of open water dives:

Location	Date	Depth	Dive time		

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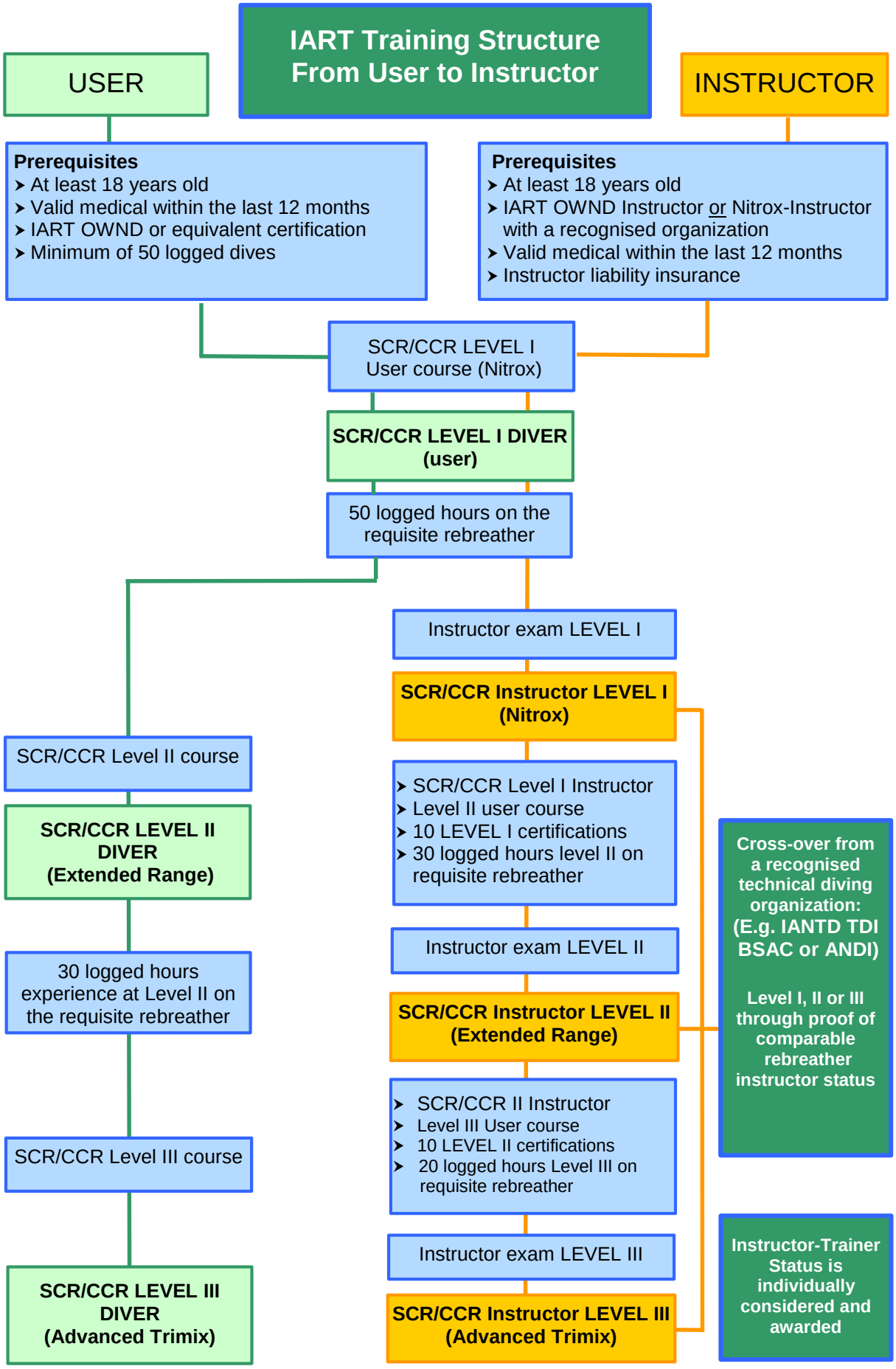
IART Training Structure
From User to Instructor
USER
INSTRUCTOR
Prerequisites
➤ At least 18 years old
➤ Valid medical within the last 12 months
➤ IART OWND or equivalent certification
➤ Minimum of 50 logged dives
Prerequisites
➤ At least 18 years old
➤ IART OWND Instructor or Nitrox-Instructor with a recognised organization
➤ Valid medical within the last 12 months
➤ Instructor liability insurance
SCR/CCR LEVEL I User course (Nitrox)
SCR/CCR LEVEL I DIVER (user)
50 logged hours on the requisite rebreather
Instructor exam LEVEL I
SCR/CCR Instructor LEVEL I (Nitrox)
SCR/CCR Level II course
SCR/CCR LEVEL II DIVER (Extended Range)
➤ SCR/CCR Level I Instructor
➤ Level II user course
➤ 10 LEVEL I certifications
➤ 30 logged hours level II on requisite rebreather
Instructor exam LEVEL II
30 logged hours experience at Level II on the requisite rebreather
SCR/CCR Instructor LEVEL II (Extended Range)
Cross-over from a recognised technical diving organization: (E.g. IANTD TDI BSAC or ANDI)
Level I, II or III through proof of comparable rebreather instructor status
SCR/CCR Level III course
➤ SCR/CCR II Instructor
➤ Level III User course
➤ 10 LEVEL II certifications
➤ 20 logged hours Level III on requisite rebreather
Instructor exam LEVEL III
SCR/CCR LEVEL III DIVER (Advanced Trimix)
SCR/CCR Instructor LEVEL III (Advanced Trimix)
Instructor-Trainer Status is individually considered and awarded

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IART, the International Association of Rebreather Trainers, was founded in 1997 after Hubert Stieve and Peter Grosserhode recognised that the growth of rebreather technology in recreational diving was not without great safety risks and organizational problems for the established recreational diver training agencies and clubs. Too great was the difference in required knowledge, ability und discipline.

IART has the aim, through uncompromising teaching standards, to further the use of Nitrox and Trimix and to make rebreather diving as safe as possible. Nothing should be left unquestioned. The aims, and the ways to achieve them, must be continually reviewed and adapted. IART will closely follow the future development of mixed gas and rebreather diving and continue to make recommendations and promptly adapt training programmes to keep pace with new technology.

President
Chris Ullmann

Board of Advisors
Chairman - N. Matthews
www.iart.de

Meet other IART divers and catch up with the latest news International Association of Rebreather Trainers Chris Ullmann (IART HQ)

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Guarantee

The first owner of the unit must return this completed guarantee form to SUBMATIX within 14 days of purchase.

All dives made with this equipment must be conducted within the limits of the Submatix Dive Planner and signed by the user and his/her dive partner. To maintain the validity of the Submatix guarantee, the owner is obliged to maintain a correctly filled-out dive logbook and submit the unit for an annually inspection to a service centre authorised by Submatix. If unauthorized modifications have been made or if the service book shows an incomplete maintenance record, Submatix accepts no liability for any damage thus ensued. SUBMATIX also accepts no liability for any damage that occurs prior to the receipt of the signed guarantee form

Serial number: .....
Purchase date: .....
Name: .....
Address: .....
Postcode, City: .....
Country: .....
Telephone: .....
Email: .....

I accept the conditions of use.

Signature:

I accept that if no other place is written in this manual, the legal domicile and the place of fulfilment is Erfurt/Germany.

Signature:

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Liability for function and/or damage to the unit

The owner or user of the unit is liable for the function of the unit and/or damage to the unit if the equipment is not correctly maintained or repaired by authorized personnel trained by Submatix. Submatix is not liable for damage caused by incorrect use of the equipment or for components supplied by other dive equipment producers!

Where notes concerning laws, decrees and standards are given, they are based on the legal regulations of Germany.

Guarantee and liability conditions related to sales and delivery cannot be extended through the above-mentioned comments!

The Submatix SCR 100 ST is a mixed gas rebreather for sport divers and it was not designed for commercial application. It was designed for fixed nitrox mixtures and the corresponding constant flow nozzle. The constant flow rates were chosen to guarantee an oxygen mixture of 20% in the breathing loop at an oxygen consumption rate of 2.25 l/min.

We recommend regularly checking the ppO_2 with a suitable ppO_2-monitoring system during the dive.

The unit may only be used after successfully completing a training course with an agency recognized and approved by Submatix. IART is such a training agency.

The unit is only certified for use in EU states. The use in other countries/states, especially United States of America and Canada, is specifically prohibited.

I have read the manual and I completely understand the content. I accept the liability for regarding function and damage.

Signature: Date:

Note!
This page must be signed and sent back to Submatix before using the rebreather independantly.

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Name:		**Submatix SCR Dive Log**
Location:	Dive site:	
Date:	Time (start of the dive):	
Buddy		

Dive data				
Repetitive dive group (RG) → before the dive / Surface interval (SI)	RG: ___/___ SI: ___ h /___ min			
CNS O_2%-dosage CNS O_{2time} • multiplier = CNS O_{2rest}	___/___ % O_{2old} • ___/___ = ___/___ % O_{2rest}			
Nitrox Mix				
Gas mixture premix → share fO_2, with it MOD	___ % O_2 ___ % N_2			
Acceptable partial pressure of O_2 → max. length of stay at ppO_{2max}	ppO_{2max} = 1.4 bar max. ___ min			
Maximum operation depth/ depth to switch → MOD (table)	MOD = ___ m			
Constant dosage (f) → max. dive time	___ l/min			
Gas supply (Q) → $Q = V_{unit} • (p_{unit} – p_{reserve})$	Q = ___ l/bar • (___ - ___) bar = ___ l			
Maximum dive time → $t_{max} = Q/f$	t_{max} = ___ l/___ l/min = ___ min			
Effort → Gas mixture in breathing bag	☐ low ☐ normal ☐ high → share of O_2 from table			
Gas mixture in breathing bag → share fN_2, with it EAD	___ % O_2 ___ % N_2			
Dive	**planned**		**Actual**	
Dive depth (D) (Bottom mix diluent)→ ambient pressure p_a	D = ___ m		D = ___ m	
Equivalent air depth → EAD (Table)	EAD = ___ m		EAD = ___ m	
No decompression limit (NDL)/ Residual nitrogen time (RNT) → determined with EAD and deco table	NDL = ___ min	RNT= ___/___ min	NDL = ___ min	RNT = ___/___ min
Rest no-decompression time (RestNDT)→ RestNDT = NDL - RNT	RestNDT = ___ min		RestNDT = ___ min	
Dive time	time = ___ min		time = ___ min	
Repetitive dive group (RG) → after the dive	RG:		RG:	
CNS O_{2new} % → of this dive	___ % O_2			
CNS O_2% after the dive CNS O_2% = CNS O_{2new}% + CNS O_{2rest}%	___ % O_2		___ % O_2	
Signature diver:				
Signature buddy:				

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